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Multipath Routing with Dynamic Load Balancing for Enhanced Energy Efficiency in Zone-Based Wireless Ad Hoc Networks

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Abstract: Mobile Ad hoc Networks (MANETs) consist of independent, self-organized mobile nodes capable of wirelessly communicating with each other in a reliable and secure manner. One of the major challenges in MANETs is energy consumption, as the lifetime of a node's battery is limited. This limitation can affect both network connectivity and the lifetime of individual nodes. Various protocols, proposed by the IETF and other solution providers, have aimed to optimize bandwidth, transmission quality, and power control, but none have significantly improved energy consumption. In response to these challenges, the proposed protocol is the Dynamic Load Balancing in Multipath Energy-Consuming Routing Protocol (DLB-MERP) for Wireless Ad hoc Networks. DLB-MERP can be viewed as an extension of the AOMDV protocol and is classified as a zone-based routing protocol, though it incorporates superior load balancing and energy management techniques. It introduces the concept of virtual zones to manage and distribute energy consumption in an organized way. The protocol selects communication paths based on the availability of node energy and power levels. A leader node is defined within each zone, chosen based on its energy level, load, and channel strength, to optimize energy usage. This method increases network resiliency through multipath routing, thereby enhancing overall network performance and extending network lifetime. DLB-MERP effectively addresses the limitations of existing energy-aware routing methodologies by balancing energy consumption, leading to prolonged network operation.

Keywords: MANETs, Zone-based Multipath Routing, Dynamic Load Balancing, Energy Consumption, AOMDV

I. INTRODUCTION

Mobile Ad hoc Networks (MANETs) are self-organized, wireless systems composed of autonomous mobile nodes [1]. The primary goal of MANETs is to establish a stable and secure communication link among wireless devices. However, a significant challenge faced by MANETs is energy consumption due to the limited battery life of the nodes in these networks. Efficient energy management is crucial to maintaining network connectivity and extending the lifespan of each node [2].

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Energy conservation is essential for sustaining the performance and longevity of wireless networks. The energy capacity of battery-powered nodes is limited, and as network traffic increases, energy consumption grows proportionally, depleting both network and node resources [3]. Therefore, two key activities for ensuring MANET sustainability are increasing network lifetime and effectively managing available node energy. Minimizing energy consumption at the node level plays a vital role in optimizing network quality and extending the lifespan of node batteries [4].

Energy consumption and network performance optimization require thorough analysis of energy and power dynamics, which must be effectively managed by routing protocols. Zone-Based Technology offers a promising solution by creating virtual zones that efficiently handle and balance energy consumption. Previous energy-aware routing protocols have failed to fully address these issues in ad hoc networks. Zone-based multipath routing provides an effective method for load balancing across energy levels, which helps to extend network lifetime.

This paper proposes the Dynamic Load Balancing in Multipath Energy-Consuming Routing Protocol (DLB-MERP) for Wireless Ad hoc Networks. Based on the AOMDV routing protocol, DLB-MERP introduces zone-based technology for energy management. It selects paths based on the availability of energy and power levels, with the aim of minimizing energy consumption while ensuring effective data forwarding. Leader nodes are selected in each zone based on energy levels and channel strength to optimize energy usage. The protocol integrates energy, distance, and power analyses to prioritize high-energy nodes and accelerate path discovery. Through the use of multipath technology, DLB-MERP enhances network resilience, improving reliability. Leader nodes play a critical role in data aggregation within zones.

The proposed DLB-MERP protocol addresses the energy consumption challenge by offering a modern routing approach that optimizes energy resources, thus improving overall network performance. The remainder of this paper is organized as follows: Section II presents the related literature review, identifying gaps in energy-efficient routing protocols. Section III provides an overview of DLB-MERP and its significance. Section IV details the design of the protocol, focusing on its zone-based and energy-aware features. Section V explains the dynamic load balancing algorithm.

Section VI presents simulation results, demonstrating the effectiveness of the proposed approach. Finally, Section VII offers conclusions and suggests areas for future work.

II. RELATED WORK

Energy conservation is a major concern in wireless networks, particularly in Mobile Ad-hoc Networks (MANETs) that utilize dynamic load balancing and multipath routing protocols [5]. This section reviews previous research focused on energy-saving techniques combined with load balancing in MANETs, analysing their advantages and limitations [6].

The paper [7] proposes a new load-balanced multipath dynamic source routing (DSR) protocol for MANETs. The protocol aims to improve routing performance by evenly distributing traffic loads across multiple paths. It addresses the challenge of load balancing in MANETs to optimize resource utilization and reduce congestion. By dynamically utilizing multiple paths, the protocol enhances data transmission efficiency and improves overall network performance. The proposed protocol offers a promising solution for load balancing in MANETs, contributing to advancements in mobile communication technologies.

The paper [8] introduces a routing protocol for wireless ad hoc networks that focuses on load balancing to enhance network performance. It proposes mechanisms for load estimation, path selection, traffic distribution, and dynamic routing table updates. Through simulations, the protocol demonstrates improved network performance, increased throughput, reduced congestion, and better load balancing compared to existing protocols. The findings underscore the importance of load balancing in optimizing resource utilization and network efficiency in wireless ad hoc networks.

The paper [9] proposes an energy-efficient load balancing approach to enhance the performance of the Ad hoc On-Demand Multipath Distance Vector (AOMDV) routing protocol in MANETs. The objective is to distribute network traffic evenly across multiple paths while considering energy constraints. The approach incorporates energy estimation, a load-balancing algorithm, path selection, and dynamic routing table updates. Performance evaluation metrics such as throughput, end-to-end delay, and energy consumption are considered. Using the NS-2 simulator, the approach demonstrates improved energy efficiency, enhanced network performance, and balanced traffic distribution compared to traditional AOMDV routing.

The paper [10] presents an advanced load balancing, congestion control, and multipath routing scheme for MANETs. The objective is to improve network performance by efficiently managing traffic and preventing congestion. The proposed approach combines load balancing techniques, congestion control mechanisms, and multipath routing algorithms. Additionally, it incorporates Random Early Detection (RED) to avoid congestion and utilizes Fractional Order Particle Swarm Optimization (FOPSO) to optimize routing paths. Performance is evaluated through simulations using metrics such as throughput, delay, and packet delivery ratio. The results demonstrate that the proposed approach effectively achieves load balancing, controls congestion, and improves the overall performance of MANETs.

The paper [11] introduces an improved version of the AOMDV routing protocol for ad hoc networks, aiming to enhance routing efficiency by incorporating load balancing mechanisms while considering energy constraints. The proposed protocol seeks to distribute traffic evenly across multiple paths, thereby reducing congestion and prolonging network lifetime. It achieves this by implementing load-balancing algorithms and energy-aware routing decisions. The performance of the protocol is evaluated using simulations, with metrics such as throughput, end-to-end delay, and energy consumption. Results show that the improved AOMDV protocol effectively balances network load, improves routing efficiency, and extends network lifetime by considering energy constraints.

The paper [12] presents a multipath routing protocol for ad hoc networks based on the AOMDV protocol. The objective is to achieve load balancing and energy efficiency in the network. The proposed protocol incorporates load balancing mechanisms to distribute traffic across multiple paths, thereby reducing congestion and improving network performance. It also accounts for energy constraints by considering the residual energy of nodes during route selection. The performance of the protocol is evaluated through simulations, with metrics such as packet delivery ratio, end-to-end delay, and energy consumption. The results demonstrate that the proposed protocol effectively achieves load balancing, enhances energy efficiency, and improves the overall performance of the ad hoc network.

The paper [13] presents a modified energy-constrained protocol based on the AOMDV routing protocol for MANETs. The objective of the protocol is to enhance energy efficiency and prolong network lifetime. The proposed protocol incorporates energy constraints by considering the remaining energy levels of nodes during route selection. It aims to balance energy consumption among nodes and prevent energy depletion in specific nodes. The performance of the protocol is evaluated through simulations, considering metrics such as network lifetime, energy consumption, and packet delivery ratio. The results show that the modified energy-constrained protocol improves energy efficiency, extends network lifetime, and maintains satisfactory packet delivery performance compared to traditional AOMDV protocols.

The paper [14] proposes a multipath routing protocol aimed at achieving load balancing and **Quality of Service** (QoS) in ad hoc networks. The objective is to distribute network traffic evenly across multiple paths, thereby improving network performance and resource utilization. The methodology includes load-balancing mechanisms and QoS considerations during path selection. The protocol is evaluated using performance metrics such as throughput, delay, and packet delivery ratio. Results show that the proposed protocol achieves load balancing, improves network performance, and ensures QoS requirements are met in ad hoc networks.

The paper [15] aims to improve load balancing and energy efficiency in ad hoc networks by considering both residual energy of nodes and load-balancing factors during route selection. The protocol dynamically balances traffic load across multiple paths while ensuring that energy-constrained nodes are not excessively utilized. Through simulations, the Load-Balancing Multipath Minimum Residual Energy AOMDV (LBMMRE-AOMDV) protocol demonstrates improved load balancing, enhanced network performance, and prolonged network lifetime compared to traditional AOMDV protocols.

The paper [16] proposes a method to improve the performance of the AOMDV routing protocol in MANETs by incorporating traffic-aware load balancing. It introduces a mechanism that monitors traffic load and dynamically adjusts routing decisions based on current network conditions. The proposed approach redistributes traffic across multiple paths to alleviate congestion and enhance network performance. Simulations show that it significantly improves throughput, reduces packet loss, and enhances network stability compared to traditional AOMDV routing.

The paper [17] proposes an energy-efficient load balancing approach for the AOMDV routing protocol in MANETs. It aims to distribute energy consumption evenly among nodes, thereby extending the network's lifetime and improving overall performance. The approach involves load estimation based on energy levels and selecting routes with lower energy consumption. Simulations show that the proposed technique significantly improves network lifetime, reduces energy consumption, and enhances performance compared to traditional AOMDV routing.

The paper [18][19][20][21][22][23] proposes an energy-aware approach for the AOMDV routing protocol in MANETs. It considers the queue length of nodes as a constraint to optimize energy consumption and improve network efficiency. The approach involves energy estimation and routing based on constrained queue length, selecting routes with unconstrained queue lengths to promote efficient energy usage. Simulations show that the proposed approach significantly improves energy consumption, network efficiency, and node lifespan in MANETs.

III. PROPOSED MODELLING

A. Problem Identification

Some of the challenges faced by routing protocols in wireless ad hoc networks include:

- **Imbalance in Energy Consumption**: Conventional routing protocols typically fail to evenly distribute the energy load across nodes. As a result, some nodes may exhaust their energy quickly while others remain underutilized.
- **Low Network Lifetime**: Unequal energy consumption leads to a shortened network lifetime. Nodes that deplete their energy can cause network partitioning, which disrupts connectivity.
- **Wastage of Multiple Paths**: Although many ad hoc routing protocols are designed for multipath routing to enhance reliability and throughput, they often fail to utilize all available paths. Instead, they rely on a single path, leaving others underutilized.
- **Lack of Dynamic Adaptability**: Static routing protocols are unable to adjust to varying network conditions, such as node mobility, energy depletion, and network congestion, leading to a decline in overall performance.

B. Objectives

To address these challenges, the objectives of DLB-MERP include designing protocols that can dynamically distribute energy load across nodes to optimize energy consumption and extend the network's lifetime. This will be achieved through the optimal use of multiple paths in the network, considering path reliability, residual energy, and network congestion to enhance overall performance and throughput.

- **Adaptive Routing**: The protocol will adapt routing decisions dynamically in response to node mobility, energy levels, and changes in network topology. The aim is to achieve energy efficiency while maintaining routing effectiveness.
- **Energy-Aware Path Selection**: Mechanisms for path selection will be based on energy efficiency. The residual energy levels of nodes along these paths will be considered to conserve energy and evenly distribute it across the network.
- **Performance Analysis**: The proposed protocol will be simulated and compared with other protocols. Metrics such as network lifetime, energy consumption, throughput, and packet delivery ratio will be evaluated to demonstrate the efficiency of the DLB-MERP protocol.

C. Dynamic Load Balancing in Multipath Energy-Consuming Routing Protocol for Wireless Ad Hoc Network (DLB-MERP)

The DLB-MERP protocol is designed to dynamically balance network load by considering multipath routing and energy consumption in wireless ad hoc networks. Since there is no centralized infrastructure in these networks, efficient resource utilization and energy conservation are essential.

DLB-MERP addresses these challenges through the following approaches:

- **Dynamic Load Distribution**: The protocol distributes network load across multiple paths, preventing overload on any single path and efficiently utilizing all available routes.
- **Energy Considerations**: It minimizes energy consumption by intelligently balancing the load, taking into account the energy levels of individual nodes and selecting paths for data transmission based on energy efficiency.
- **Improved Performance**: DLB-MERP optimizes energy utilization during data transmission, enhancing overall network performance and extending network lifetime through effective load balancing.

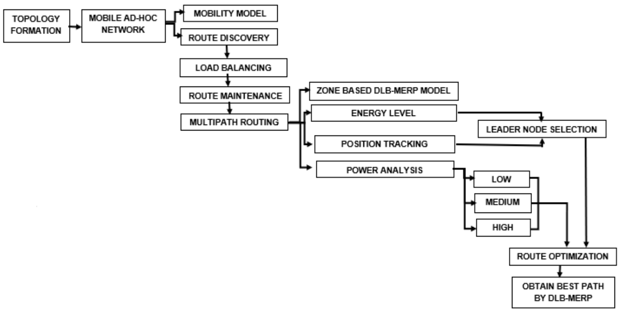

Figure 1: Block Diagram Depiction of DLB-MERP

Figure 1 below illustrates the block diagram, where the MANET is represented using the Random Mobility model. Multiple paths exist between the source and destination, but optimized path selection is essential for efficient load balancing. The zone-based model in DLB-MERP selects the most efficient path by considering energy efficiency and load distribution. This is achieved through energy labelling, position tracking, and power analysis, ensuring that load balancing techniques are effectively applied.

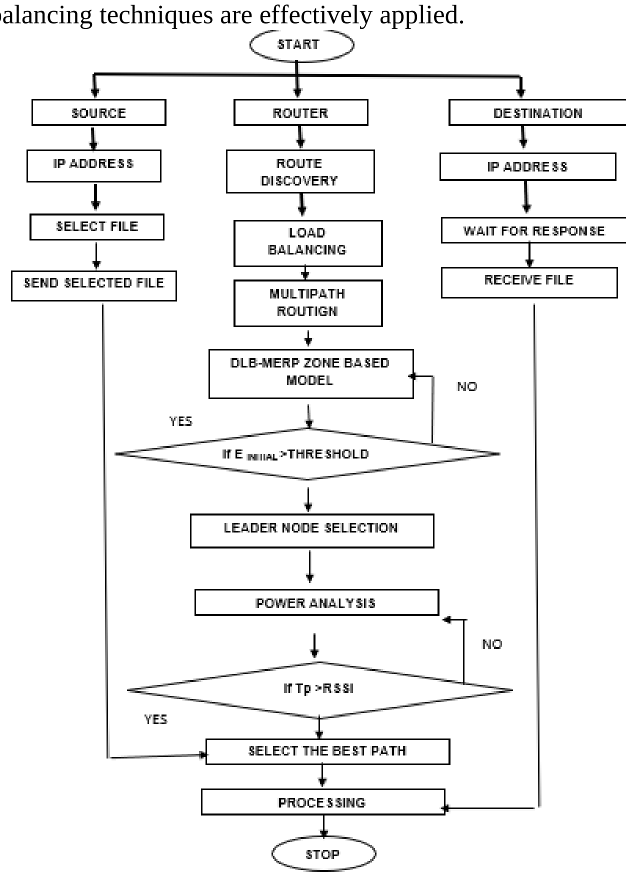

Figure 2: Flow Chart of DLB-MERP

The protocol takes into account zones created by member nodes and the leader node during path selection. This selection process is based on energy labelling and position tracking, ensuring that the leader node efficiently manages its zone. Load balancing is also a key factor, distributing the network load evenly. When selecting a leader node, energy labelling and position tracking are prioritized, while power analysis—classified into low, medium, and high levels—is used to identify the most suitable node for data transmission.

D. Methodology

The proposed methodology employs network load-balancing techniques to evenly distribute the workload across nodes in a mobile ad hoc network. To optimize resource utilization, the system follows these steps:

- **Network Creation**: Establish a network with NNN nodes, designating specific nodes as sources and destinations.
- **Mobility Model Application**: Implement a random mobility model for each node to define its position and velocity. Calculate the speed based on previous positions.
- **Node Updates**: Update the range and power details for each node.
- **Workload Monitoring**: Monitor the workloads of all nodes in terms of active connections, processing capabilities, and available resources. Only leader nodes that meet power thresholds and can equalize workloads should be considered for managing the load at each node.
- **Leader Node Selection**: Prefer nodes with low workloads and sufficient energy levels for leader roles.
- **Power Analysis**: Leader nodes perform power analysis of neighbouring nodes by computing their power levels and workloads.
- **Transmission Power Calculation**: Calculate transmission and reception power for each node based on workload factors.
- **Load-Aware Power Analysis**: Conduct a load-aware power analysis that prioritizes nodes with low workloads and adequate power reserves.
- **Node Selection**: Execute node selection to establish communication paths based on this power analysis while considering load balancing.
- **Forwarder Node Assessment**: Assess the selected forwarder nodes to ensure they can handle additional traffic without becoming overloaded, taking into account RSSI, node density, range, and workload distribution.
- **Finalization**: Once the forwarder nodes are selected and the communication routes or channels are determined, proceed with the established pathways for data transmission.

E. Load-Balancing

Achieving effective load balancing in Mobile Ad Hoc Networks (MANETs) is a complex task due to their constantly changing topology and unpredictable nature. It is crucial to evenly distribute the network load to prevent the overburdening of specific nodes. Poor load management can lead to heavily loaded nodes becoming bottlenecks, resulting in network congestion, increased latency, and overall performance degradation.

In the load-balancing phase of DLB-MERP, the refinement of discovered paths is performed using equations (1) and (3). A path, denoted as x_i, with maximum nodal residual energy ξ_i greater than or equal to the energy needed to transmit the minimum number of packets the path can handle ($\xi_i \geq P_{xi}$) is added to the source cache; otherwise, it is discarded:

$$\xi_i = \min_{j\epsilon k} E_{jx_i}, \quad (1)$$

where ξ_i represents the maximal nodal residual energy of path x_i, and E_{jxi} is the residual energy of j along path x_i.

The energy required to transmit one packet is determined using equation (2):

$$P = \sum_{j=1}^{R-1} E_{(n_j, n_{j+1})}, \quad (2)$$

where E is the energy consumed per hop, and $n_j,\dots,n_{R-1}$ are the nodes along the path.

Additionally, the energy for transmitting packets over the path is calculated using equation (3):

$$P_{x_i} = T_p \times \frac{E_p}{n}, \quad (3)$$

where T_p is the total number of packets, and P_{x_i} represents the energy required for the minimum number of packets path x_i can process.

After refining, the paths in the source cache are ordered by descending path speed S_{x_i}, and packets are routed based on the speed ratio to the total speed of all paths, as defined by equations (4) and (5):

$$S_{x_i} = \min_j \left(\frac{C_j}{\sum_{K\epsilon N_j} F_{jk}} \right), \quad (4)$$

where m is the number of nodes in path x_i, C_j is the capacity of node j, F_{jk} represents the traffic flow from node j to its neighbouring node k in bits/second, and F_{kv} represents the flow from node k to its neighbouring node v.

The number of packets to be sent over a path x_i is given by equation (6):

$$PL_{x_i} = T_p \times \frac{S_{x_i}}{\sum_{i=1}^{T} S_{x_i}}, \quad (5)$$

where T_p is the total number of packets, and T is the number of paths stored in the cache?

F. Flow Chart for DLB-MERP

Multipath routing in Mobile Ad Hoc Networks (MANETs) presents significant challenges due to the constantly changing network topology and varying link capacities. The mobility of nodes affects network efficiency, particularly regarding energy consumption and overall network lifetime. To address these issues, the Zone-Based Leader Election Energy Constrained AOMDV Routing Protocol (DLB-MERP) has been developed. This innovative multipath routing protocol enhances performance by integrating load balancing techniques, setting it apart from traditional methods. DLB-MERP improves upon conventional AOMDV protocols by refining their routing processes, and its functionality is illustrated in a flowchart.

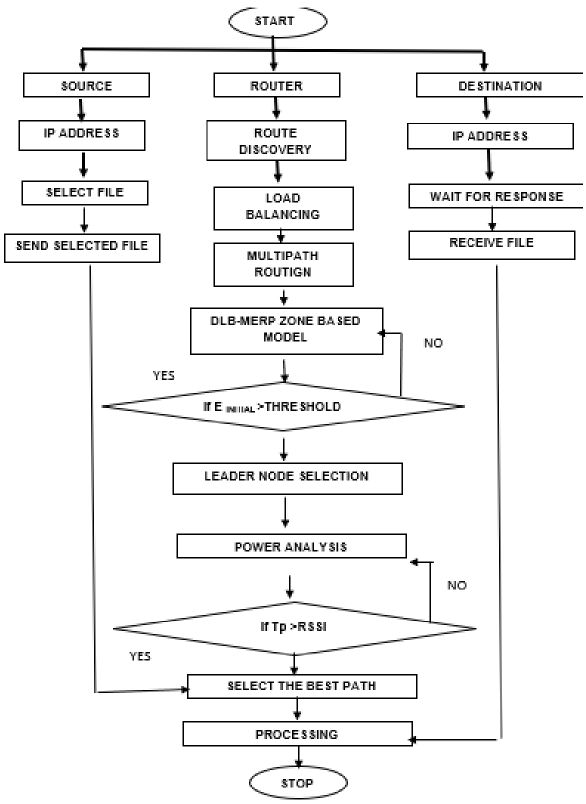

Figure 3: Flow Chart of DLB-MERP

Figure 3 illustrates the flow of functions as outlined in the flowchart of the proposed system. The energy model applied in the network utilizes Mobile Ad Hoc Networks (MANETs) to derive a threshold value based on the energy information from all nodes. This threshold is used to assess the transmission capacity of each node. Each node is assigned an energy label that gradually decreases over time. When a node's energy label falls below the threshold, it is deemed incapable of transmission, and only those nodes with energy labels meeting or exceeding the threshold are considered for communication. The node with the highest energy level is selected as the leader.

The key steps in selecting the leader node are as follows:

1. Create zones within the wireless network.
2. Collect energy information from nodes within each zone to measure their energy levels.
3. Set the threshold value.
4. Define a counter time to specify how long a node should serve as the zone head (e.g., 30 seconds).
5. Select the node with the highest energy level as the leader.
6. Periodically re-evaluate and select the node with the next highest energy level when needed.

Load balancing is integrated into this selection process to evenly distribute network traffic, preventing any single node from becoming overloaded. This strategy helps maintain balanced energy consumption across the network.

Additionally, power analysis is conducted to evaluate both transmission and reception power. If the transmission power cost exceeds the received signal strength (RSS), an alternative route is selected.

By implementing these measures, the DLB-MERP protocol enhances overall performance, improves energy conservation, and increases data transmission efficiency across the network.

G. Proposed Algorithm

In DLB-MERP algorithm, zone-based technology has been utilized to enhance the wireless networking communication. Broad steps involved are as below:

```
// Network Initialization
Initialize src, dst
// Mobility Model
FOR each node pair (i, j) IF movement exists between nodes i and j
   Calculate vel (i, j) using mi (Si, Sj)
   Calculate speed between nodes i and j based on positions
// Leader Node Selection with Load Balancing
FOR each node in the network
   Update Range (Ei, pi) and Pi
   FOR each neighboring node db
      IF Pi of node nid is higher
         Set forward path k (i, j) from src to node nid
   IF Ei of node is higher
      Consider node as potential leader node mn (Ei)

// Power Analysis
FOR each leader node
   Analyze power levels of neighboring nodes
   FOR each node ni in the group
      Calculate ti(n) and ri(n)
   Calculate transmission ti and reception power ri of each node

// Forwarder Node Selection
FOR each node in nodeList
   Select forwarder candidates based on nid and power of neighboring nodes nid (1)
   FOR each node in network range
      IF RSSI > maxDensity OR (newDensity == RSSI AND range < size)
         Set maxDensity and maxIndex to high level
         Set max_pktsize to normal level
         Set max_iterations to low level

// End Process
End
```

The process begins with the initialization of source and destination nodes within the network. The mobility model is then applied to calculate the velocity and speed between nodes based on their positions. Leader nodes are selected by updating their range and power information, with nodes exhibiting higher energy levels prioritized for leadership roles to ensure effective load balancing.

Power analysis is conducted by evaluating the transmission and reception power levels of neighbouring nodes to optimize energy usage. Forwarder nodes are chosen based on factors such as Received Signal Strength Indicator (RSSI) and node density, ensuring efficient data forwarding while preventing network overload.

The process concludes by setting the appropriate parameters for maximum density, packet size, and iterations to ensure optimal network performance.

The DLB-MERP algorithm integrates these steps, facilitating better communication and workload distribution to enhance network performance. By balancing the load, it optimizes resource utilization and reduces congestion, making the wireless ad hoc network more effective and viable. The adopted methodology in this research is outlined here.

H. Explanation of Simulation Environment & Experimental Setup

In this research, the performance of the routing protocols—namely, DLB-MERP, AOMDV, and AODV—has been evaluated concerning energy consumption and load balancing within a zone-based network. The simulations conducted in this study utilize the Network Simulator - ns2 (NS-2 Version 2.35) as the research methodology. This approach is chosen due to the high costs, time-consuming nature, and inflexibility associated with real MANET deployments.

Several publicly available tools for assessing and evaluating protocol capabilities include Glomosim, Qualnet, ns2, and OPNET. This work specifically employs the NS2 simulation tool, developed by the University of California, Berkeley.

Figure 4 illustrates the overall simulation workflow, outlining the key steps involved in the performance analysis of the protocols under consideration.

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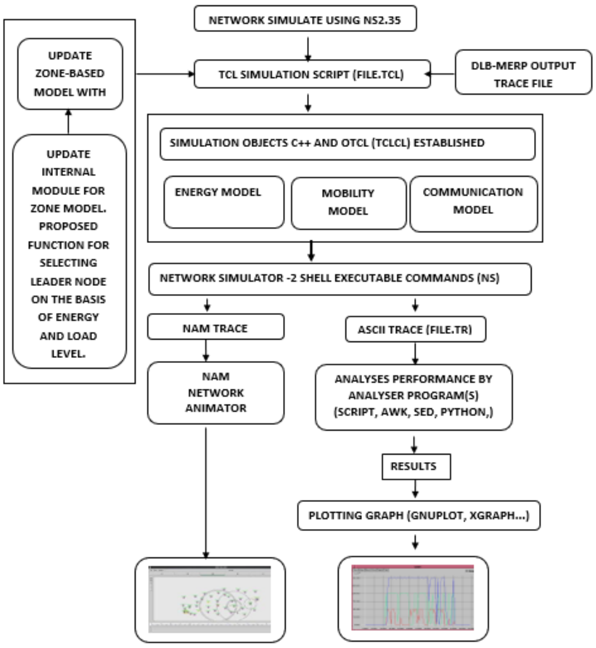

Figure 4: Architecture of the Proposed Study

NS-2 is a versatile discrete-event network simulator developed in C++ and TCL, where the network's behavior is defined through TCL scripts. The results of the simulations are obtained by analyzing the output trace files, which provide various performance metrics.

Mobile ad hoc networks can be simulated using several tools, including OPNET, Qualnet, and NS2. However, this study utilizes NS2 due to several advantages:

- **Free and Open-Source**: NS2 is open-source software, making it freely available for research and simulation purposes.
- **Easy Installation**: The simulator can be easily downloaded and installed with minimal effort.
- **Programming Flexibility**: It allows for programming in C++, facilitating customization and extensions.

The performance measurements collected from these simulations are analyzed to study the behavior of the protocols under different scenarios.

IV. METHODOLOGY ADOPTED

A. Description of Simulation Environment & Experimental Setup

This research paper scrutinizes the behaviour and performance of the DLB-MERP, AOMDV, and AODV routing protocols concerning energy consumption and load balancing in zone-based networks. Simulations are conducted using NS-2 Version 2.35 (Network Simulator). The choice of simulation over real MANET deployment is motivated by the high costs and inflexibility associated with physical testing. While several simulators, including Glomosim, Qualnet, and OPNET, were considered, NS2 was selected due to its extensive support and functionality.

B. Performance Metrics

These performance evaluation measures are:

• Throughput: The number of successful messages passing through the network for every measure noted in bits per sec or packets per sec. The equation for this is:

$$Throughput = \frac{TotalDataReceived}{TotalTime}$$

- **Energy Consumption:** Energy consumed by all nodes in the network for the whole simulation period. Energy consumed can be calculated as:

$$Energyconsumption = \sum(EnergyperBit \times NumberofBitsTransmitted)$$

- **Network Lifetime:** Time from the start of simulation to termination of a network because its energy is completely exhausted. It can be calculated as:

$$NetworkLifetime = \frac{\sum of\ NodeLifetimes}{NumberofNodes}$$

These metrics reveal insights into protocol behaviors and efficiency across different scenarios.

C. Simulation Parameters

To simulate the protocol, specific parameters were defined in the TCL script of the network, as outlined in Table 1. This table presents the simulation parameters utilized during the evaluations. The performance assessment was conducted using the NS2.35 simulator, with the following simulation parameters:

Table 1: Simulation Parameters

Parameters	Value
Simulator	NS2.35
Simulation Area	1507 m x 732 m
Number of Nodes	50, 75 and 100 nodes
Node Speed	5 m/s
Queue Size	50 packets
Studied Routing Protocols	AODV, AOMDV, DLB-MERP
Data Payload	512 bytes/packet
Initial Energy	50 joules
Idle Power	0.100 J/bit
Sense Power	0.0175 J/bit
Energy Consumption (Transmit)	0.035 J/bit
Energy Consumption (Receive)	0.035 J/bit
Traffic Type	CBR
Simulation Time	500 secs
Channel Type	Wireless channel
MAC Type	802.11
Mobility Model	Random Waypoint
Antenna Model	Omni

D. Results and Discussion

This section presents the simulation results obtained by executing the protocols within the NS2.35 simulator. Figure 5 displays screenshots of the network topology captured during the simulation runs for the DLB-MERP protocol. These simulations were implemented and tested across various scenarios, maintaining identical parameters for performance evaluation.

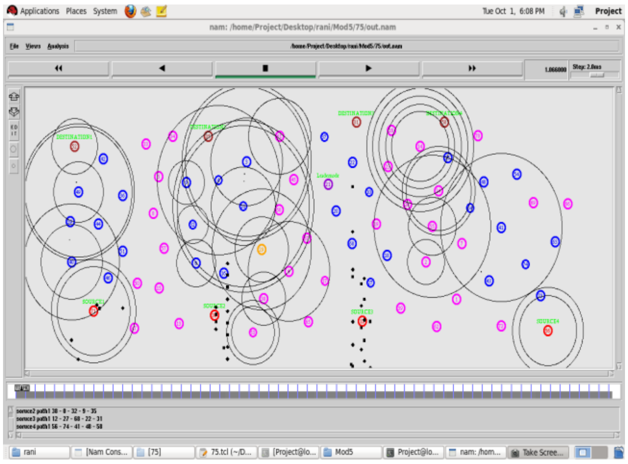

Figure 5: Network Simulator Windows

The following scenarios were considered for the simulation:

- **Number of Nodes:** 50, 75, 100, and 600 nodes.
- **Linear Node Speed:** Set at 5 m/s.
- **Packet Size:** 512 bytes.

The performance metrics used for evaluation include:

- **Throughput**
- **Energy Consumption**
- **Network Lifetime**

i. Throughput Evaluation

Throughput represents the speed at which messages are successfully transmitted, typically measured in bits per second (bps) or packets per second. Several scenarios, including varying node counts and throughput levels, have been analyzed.

- **Table 2** highlights the throughput comparison between the DLB-MERP, AODV, and AOMDV protocols.
- Additional comparative data is presented in **Table 3**.
- These findings are visually depicted in **Figure 6**.

In all scenarios, DLB-MERP consistently demonstrated superior throughput due to its efficient routing mechanism, achieving average energy savings of **58.94%** compared to AODV and **49.43%** compared to AOMDV.

Table 2: Throughput of AODV, AOMDV, and DLB-MERP at Different Number of nodes

Protocols	50	75	100
AODV	6542.33	9047.52	9523.68
AOMDV	6912.18	9284.17	15532.75
DLB-MERP	13045.72	22981.22	26692.14

Table 3: Throughput Comparison of DLB-MERP with AODV and AOMDV

Number of Nodes	50	75	100	Average/Overall
DLB-MERP vs AODV	49.85%	60.63%	64.33%	58.94%
DLB-MERP vs AOMDV	47.02%	59.59%	41.69%	49.43%

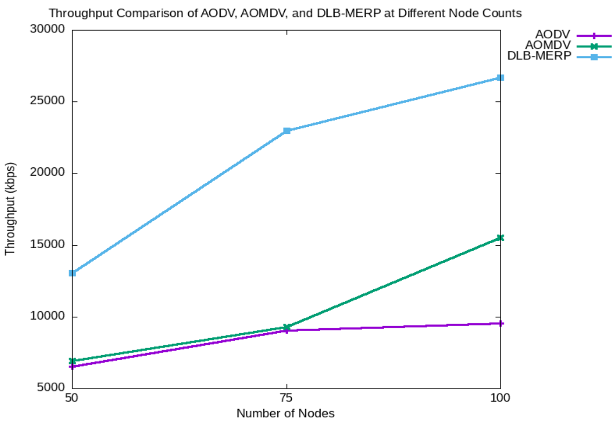

Figure 6: Throughput Comparison

ii. Throughput Analysis

DLB-MERP outperforms both AODV and AOMDV in scenarios with varying numbers of nodes, thanks to its zone-based approach and dynamic load balancing. By adjusting node selection based on energy levels and distributing traffic across multiple paths, DLB-MERP efficiently manages increasing node counts. This prevents overload and ensures high network performance. Its adaptability allows DLB-MERP to maintain superior throughput and network efficiency, even as the number of nodes increases.

iii. Energy Consumption Evaluation

Energy consumption refers to the total energy utilized by the nodes within the network and is a critical factor in extending the network's lifespan. In ad hoc networks, where nodes are battery-powered, energy consumption directly impacts the network's longevity. Various scenarios, focusing on the number of nodes and their speed, have been analysed to assess energy consumption relative to node count.

Table 4 compares the energy consumption of DLB-MERP, AODV, and AOMDV, while Table 5 presents additional comparative data. These results are further illustrated in Figure 7. In all scenarios, DLB-MERP consistently demonstrated lower energy consumption due to its efficient routing mechanisms, achieving average energy savings of 8.33% compared to AODV and 8.43% compared to AOMDV.

Table 4: Energy Consumption of AODV, AOMDV, and DLB-MERP at Different Number of Nodes

Protocols	50	75	100
Aodv	92.3178	153.425	190.648
Aomdv	93.1256	154.912	191.533
Dlb-Merp	71.5649	150.728	170.485

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Table 5: Energy Consumption Comparison of DLB-MERP with AODV and AOMDV

Number of Nodes	50	75	100	Average/Overall
DLB-MERP vs AODV	22.49%	1.76%	10.59%	11.61%
DLB-MERP vs AOMDV	23.17%	2.70%	11.01%	12.29%

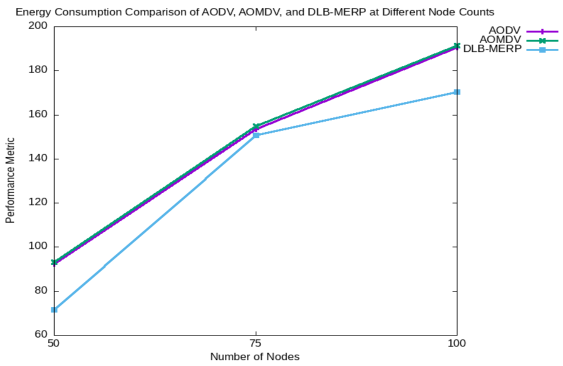

Figure 7: Energy Consumption Comparison

iv. Analysis of Energy Consumption

Here's a polished version of your text on DLB-MERP's energy consumption optimization:

In scenarios with varying numbers of nodes, DLB-MERP optimizes energy consumption by ensuring even traffic distribution across routes with higher energy levels. This approach prevents individual nodes from becoming overloaded, unlike AODV and AOMDV, which typically rely on single paths for data transmission. By selecting high-energy leader nodes for traffic management, DLB-MERP conserves overall network energy, leading to enhanced efficiency and an extended network lifetime as the number of nodes increases.

v. Network Lifetime Evaluation

Network lifetime refers to the duration for which a network operates efficiently, measured as the time until the nodes in the network deplete their energy. Table 6 presents a comparison of network lifetime among DLB-MERP, AODV, and AOMDV under the specified scenarios. Table 7 highlights a comparative analysis of the protocols. Figure 8 illustrates the simulation results, demonstrating that DLB-MERP significantly extends network lifetime compared to AODV and AOMDV, with an average improvement of 24.31% over AODV and 21.28% over AOMDV, even across varying node speeds.

Table 6: Network Lifetime of AODV, AOMDV, and DLB-MERP at Different Number of nodes.

PROTOCOLS	50	75	100
AODV	40.5000	41.2500	20.0000
AOMDV	41.0000	40.5000	21.0000
DLB-MERP	45.0000	42.0000	32.0000

Table 7: Network Lifetime Comparison of DLB-MERP with AODV and AOMDV

Number olf Nodes	50	75	100	Average/Overall
DLB-MERP vs AODV	11.11%	1.81%	60.00%	24.31%
DLB-MERP vs AOMDV	9.76%	3.70%	52.38%	21.28%

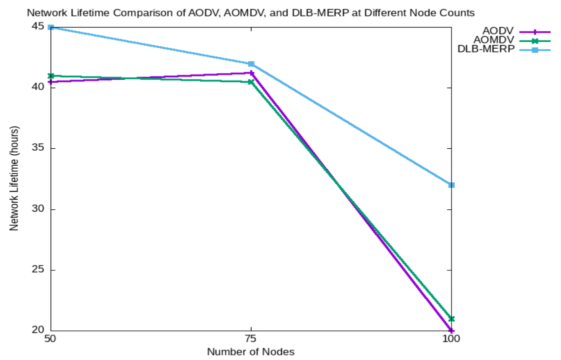

Figure 8: Network Lifetime Comparison

vi. Analysis of Network Lifetime

In scenarios with varying numbers of nodes, DLB-MERP consistently achieves a longer network lifetime compared to AODV and AOMDV. Its energy-efficient node selection and dynamic load balancing effectively distribute traffic across multiple paths, preventing rapid energy depletion in individual nodes. This balanced approach reduces stress on each node, thereby prolonging their lifespan. In contrast, AODV and AOMDV lack effective load management, which leads to quicker energy depletion of nodes. Consequently, DLB-MERP stands out as a superior choice for enhancing network lifetime.

V. CONCLUSION

This paper offers a strong introduction to DLB-MERP by outlining its key advantages over existing protocols, particularly in terms of energy efficiency, throughput, and network lifetime. The DLB-MERP protocol enhances energy management by implementing effective load balancing and zone-based routing, which together help to extend node lifetimes and improve overall network performance.

To fully assess its practical effectiveness, further testing of the DLB-MERP protocol in real-world MANET environments is necessary. Future research could also explore additional energy-saving techniques to further boost the performance and efficiency of the protocol.

DECLARATION STATEMENT

After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

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- **Funding Support:** This article has not been funded by any organizations or agencies. This independence ensures that the research is conducted with objectivity and without any external influence.

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