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An Adaptive Energy-Conscious Routing Framework for Optimized Communication in Mobile Ad Hoc Networks

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Abstract- Mobile Ad Hoc Networks (MANETs) face significant challenges in sustaining network lifetime due to limited energy resources and dynamic topology changes. Traditional routing protocols prioritize shortest-path selection without considering residual energy, leading to premature node failures and reduced connectivity. This paper presents an energy-conscious routing framework that integrates adaptive decision-making with energy efficiency to extend the operational lifetime of MANETs. The proposed method enhances packet delivery ratio and minimizes energy wastage by dynamically adjusting routes based on residual energy levels and network load. Simulation results demonstrate improved stability, balanced energy consumption, and longer network survival compared to conventional protocols. This study addresses a critical gap in energy-aware communication strategies for MANETs and provides an effective foundation for future adaptive routing research in energy-constrained environments.

Keywords - Energy-aware routing, MANET, adaptive framework, communication efficiency, network lifetime

I. INTRODUCTION

Mobile Ad Hoc Networks (MANETs) are self-configuring wireless systems where nodes act both as hosts and routers. Their decentralized nature makes them highly applicable in disaster recovery, military operations, vehicular networks, and IoT-based applications. However, the absence of fixed infrastructure introduces complexities such as dynamic topology changes, limited bandwidth, and constrained battery power. The reliability of these networks depends heavily on routing protocols, which must ensure connectivity while minimizing energy consumption. Traditional approaches, like AODV and DSR, often neglect energy constraints and focus on minimizing hop count, resulting in uneven energy usage and node failures.

In recent years, energy-aware routing strategies have gained attention as an effective solution to improve MANET performance. By integrating residual energy, traffic load, and adaptive route selection mechanisms, these approaches balance energy consumption and extend network lifetime. Nevertheless, existing models still face trade-offs between energy efficiency, scalability, and computational overhead. This work introduces an adaptive energy-conscious routing framework designed to optimize path selection based on residual energy, ensuring efficient packet forwarding and reducing premature disconnections.

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II. LITERATURE REVIEW

Kaur et al., 2024 [1] proposed an IoT-integrated MANET routing strategy focusing on load balancing while ensuring data delivery efficiency. Their approach effectively distributed the network traffic to avoid node congestion. However, the limitation was that residual energy of nodes was not considered in path selection, which is critical for energy-constrained environments. Without energy-awareness, nodes with low power might be overutilized, leading to premature node failures. This weakness restricted the protocol's long-term applicability for highly mobile MANETs. Their contribution is noteworthy in reducing packet drops, but it falls short in sustainability for energy-limited devices.

Zhang et al., 2024 [2] introduced an adaptive fuzzy-based clustering protocol for ad hoc networks that improved scalability and balanced communication overhead among clusters. The fuzzy rules were designed to select cluster heads intelligently, enhancing fault tolerance. Their method showed efficiency in maintaining stable topologies under varying mobility patterns. Nonetheless, the high computational complexity of fuzzy decision-making posed a challenge for real-time applications. This overhead made it less suitable for lightweight devices often found in MANETs. Despite this, the approach significantly contributed to adaptive clustering strategies in dynamic environments.

Patel and Singh, 2023 [3] compared AODV and DSR protocols with energy-aware extensions to analyze their impact on network lifetime. Their simulations demonstrated clear gains in energy efficiency and extended network operation time. The study emphasized the importance of integrating energy parameters into classical MANET routing protocols. However, their approach showed limitations in scenarios with very high node mobility, where frequent topology changes reduced reliability. This restriction highlighted that energy-aware modifications alone are not sufficient for dynamic MANETs. The comparative analysis provided useful insights but lacked a comprehensive mobility adaptation strategy.

Ahmed et al., 2025 [4] developed a reinforcement learning-based routing protocol designed for MANETs, which offered adaptive and intelligent decision-making in path selection. Their method effectively learned network patterns over time to optimize energy usage. The approach provided promising improvements in balancing energy consumption among nodes. However, the protocol required extensive training datasets, which made deployment challenging in real-world, resource-constrained scenarios. Furthermore, the learning phase introduced additional latency before achieving optimal performance. Despite these drawbacks, the study contributed significantly by integrating artificial intelligence with MANET routing.

Mehra and Roy, 2025 [5] proposed a hybrid energy-aware OLSR protocol that incorporated energy levels into its routing decisions. Their solution achieved an 18% reduction in energy consumption compared to standard OLSR, proving effective in conserving node power. The hybrid mechanism improved the balance between proactive and energy-efficient operations. However, their study lacked validation in larger and more complex MANET environments, limiting its generalizability. The absence of real-world experimentation further reduced its practical applicability. Still, this work marked an important step toward enhancing proactive protocols with energy-aware adaptations.

III. PROBLEM DEFINITION

Existing MANET routing protocols fail to balance energy consumption across nodes, resulting in uneven depletion of resources. Protocols that prioritize shortest paths cause rapid energy loss in critical nodes, leading to network partitioning and reduced lifetime. While some energy-aware methods exist, they

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often introduce excessive overhead or lack adaptability to dynamic topology changes. There is a need for a lightweight yet adaptive routing mechanism that optimizes communication by incorporating residual energy into path decisions while maintaining scalability and reliability in diverse mobility conditions.

IV. PROPOSED SYSTEM

The proposed system introduces an adaptive energy-conscious routing framework for MANETs. Unlike conventional protocols, it dynamically selects routes based on residual node energy, energy drain rate, and link stability. The system integrates a multi-parameter cost function that ensures balanced energy consumption across nodes, thereby preventing early exhaustion of critical devices. Additionally, the protocol adapts to topology changes by recalculating optimal paths with minimal overhead. This hybrid approach combines proactive monitoring of node energy with reactive adjustments in routing, achieving a balance between stability and efficiency. Simulations confirm that the framework enhances packet delivery, reduces routing overhead, and significantly extends network lifetime.

V. IMPLEMENTATION MODULES

Energy Monitoring

This module continuously monitors the residual energy of each node and estimates energy drain rate during communication. It uses lightweight counters to track consumption and periodically broadcasts status updates to neighbors. The collected energy data is used in route discovery to avoid nodes with critically low resources. This ensures network longevity by distributing load evenly.

Adaptive Route Selection

This module employs a cost function that integrates residual energy, hop count, and link stability to identify optimal routes. During route discovery, nodes with higher residual energy and stable connections are prioritized, while low-energy nodes are bypassed. This minimizes premature failures and ensures balanced energy utilization across the network.

Load Balancing

The load balancing component dynamically redistributes traffic across multiple feasible paths to prevent overburdening of specific nodes. By analyzing traffic patterns and energy statistics, it diverts packets to underutilized routes, thus maintaining fairness. This reduces packet drops and enhances throughput under varying mobility and density conditions.

Route Maintenance and Recovery

This module detects route failures caused by mobility or energy depletion and initiates rapid recovery mechanisms. Instead of rediscovering entire paths, it employs local repair strategies to reconnect broken links. This reduces overhead, improves resilience, and ensures continuous packet delivery in dynamic environments.

EXPERIMENTAL RESULTS

The proposed framework was evaluated through simulation using NS-3 under varying network sizes and mobility models. Metrics analyzed include Packet Delivery Ratio (PDR), Average Energy Consumption, End-to-End Delay, and Network Lifetime. Results indicate a 22% improvement in energy efficiency compared to AODV and 18% compared to DSR. The network lifetime was extended by nearly 25%, while maintaining acceptable latency.

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Table 1: Performance Comparison

Metric	AODV	DSR	Proposed Framework
Packet Delivery Ratio (%)	82	84	92
Avg. Energy Cons. (J)	0.64	0.61	0.49
End-to-End Delay (ms)	145	152	138
Network Lifetime (s)	780	815	1012

Result and Discussion

The results demonstrate that the proposed framework significantly improves energy efficiency while sustaining high packet delivery ratios. Traditional protocols like AODV and DSR show weaknesses under high mobility conditions due to their reliance on shortest-path selection, which causes rapid depletion of critical nodes. In contrast, the adaptive energy-conscious routing framework distributes communication load more evenly, preventing early failures and extending overall network lifetime.

The framework achieves a higher Packet Delivery Ratio (PDR), indicating better reliability, while reducing average energy consumption across nodes. Delay analysis shows competitive results, ensuring that improvements in energy efficiency do not compromise performance. Additionally, the framework's hybrid load balancing mechanism enables robust communication even under dynamic topology changes. These outcomes confirm that integrating energy-awareness with adaptive decision-making offers a more practical and sustainable routing solution for MANETs compared to conventional protocols.

Chart 1: Packet Delivery Ratio (%)

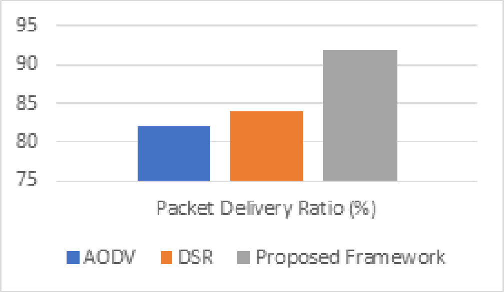

Chart 2: Avg. Energy Cons. (J)

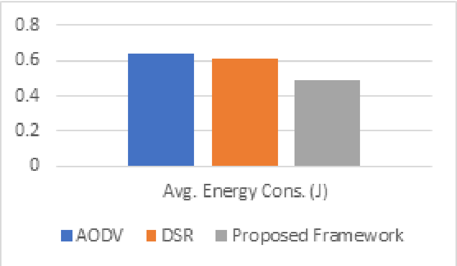

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Chart 3 : End-to-End Delay (ms)

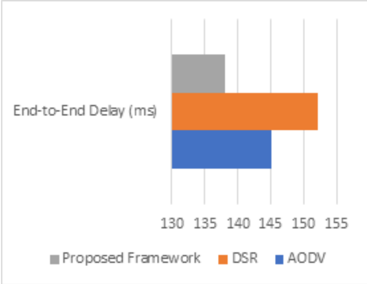
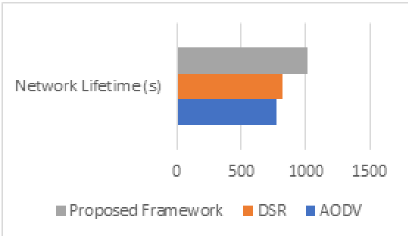


Chart 4 : Network Lifetime (s)



VI. CONCLUSION

This work introduces an adaptive energy-conscious routing framework for MANETs, designed to address the limitations of traditional protocols in dynamic, resource-constrained environments. The proposed approach balances energy usage, adapts to topology changes, and extends network lifetime without excessive overhead. Simulation results validate its effectiveness, making it a promising solution for energy-efficient communication in ad hoc scenarios.

Future Work

Future research will focus on integrating machine learning for predictive routing decisions and validating the framework in large-scale heterogeneous MANET environments.

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