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Energy-Efficient Algorithms for Prolonging Network Lifetime in MANETs

M V Narayana
Professor
Guru Nanak Institutions Technical Campus,
Hyderabad, India

T Madhu
Professor
Sri Venkateswara Engineering College
Suryapet, India

S Madhu
Professor
Guru Nanak Institutions Technical Campus,
Hyderabad, India

Abstract: MANET is a dynamic self-configuring, decentralized network, manet here stand for a mobile ad-hoc network which commonly described as node who serves as routers aimed to route the packets throughout the network. The energy of all the nodes in MANETs depletes with utilization due to which network lifetime is considered a major challenge, that no one can take part in any operation of network except those operations whose main goal is not related with data transmission. This paper suggests a set of energy-efficient techniques to control the routing, data transmission and node operations that aim at longer network lifetime. These are realized through adaptive energy-aware routing protocols which tend to choose paths with homogeneous energy utilization and refrain from unnecessarily loading specific nodes. The design leverages a novel energy prediction model for modeling future energy consumption based on workload and traffic patterns, allowing reconfigurations ahead of time. In addition, with our optimized transmission scheduling strategy, we avoid redundant transmissions by adjusting transmission power according to the distance between a pair of nodes and link quality over time. These techniques can be further leveraged with collaborative sleep-scheduling mechanisms, in which dormant nodes transition to low-power states while preserving network connectivity. Simulation — Detailed simulations were performed using ns3 to evaluate the algorithms under different mobility scenarios and traffic loads. The findings show that these methods can lead to substantial reductions — up to 35% lower overall energy consumption compared with baseline protocols — in the amount of energy used. Average improvement of 40% in network life time is gained by the algorithms and their packet delivery ratio is ensured with reliability while being energy efficient. By providing the fundamental trade-offs between energy efficiency and network performance, our results contribute to the design of sustainable MANETs for a wider range of applications. The proposed algorithms serve as a strong framework to prolong the network lifetime and are well-suited for energy constrained environments such as disaster recovery, military operations, and remote sensor networks. Future work may investigate the application of machine learning models into energy-efficient decision-making in dynamic MANET scenarios.

Keywords: Energy Efficiency; MANETs; Network Lifetime; Adaptive Routing; Power Optimization

1. INTRODUCTION

Since MANETs do not require any infrastructure due to their dynamic nature, they have become an indispensable technology in wireless communication for multiple applications. Mobile ad hoc networks are the latest AUTO networks that can provide services for use in situations where no fixed installation is available, or only impossible to lay cabling, such as disaster recovery, military operations and remote sensing. But because of its decentralization and power restriction, MANET causes quite a few demanding situations. In a MANET, every node is driven by limited battery capacity and the exhaustion of this can provoke network partitioning and lessened performance. As a result, energy consumption is becoming a key concern in MANET research as the operational efficiency of a node influences directly its network reliability and utility.

MANETs possess a decentralized and dynamic topology which significantly increases the energy management challenges. As a result, nodes can move in and out of coverage areas quickly, causing frequent changes to the network topology and thus requiring route information to be constantly updated. This hotspot problem is the uneven energy consumption among nodes --rolling-cent--as nodes involved in high-traffic routes using up their reserved power at a faster pace than others. This in turn leads to Communication bottlenecks and network fragmentations. Moreover, energy conservation techniques are sources of trade-offs in latency, throughput and reliability to minimize energy use thus increasing the complexity of finding optimal solutions. Hence, an open research issue in MANET is to design algorithms which minimize energy, and the algorithm should also have good performance. As for the efficiency of energy saving, several schemes have been introduced into MANETs like energy-aware routing, power control mechanism, clustering and sleep scheduling techniques. These approaches seem promising though very often fail to meet the intricate and constantly evolving specifications of real-world MANET applications. For instance, energy aware routing protocols such as Minimum Energy Routing (MER) algorithm while choosing a path to minimize the energy consumed but destine nodes to exhaust early. Similarly, clustering obviously reduction communication overhead but also requires re-electing cluster head frequently consequently causes extra energy and computational costs etc. However, sleep scheduling may lead to undesired asynchronization and low connectivity. It is underlined by these constraints that we require even more all-inclusive and versatile electricity management approaches.

Moreover, due to the progress of computing technologies, MANETs can be addressed in a variety of ways using the newer technologies that may never have been possible even just a few years ago. Incorporating machine learning (ML) strategies have proven to be especially productive for predicative and adaptive management of energy consumption. Reinforcement learning has been employed to dynamically optimize routing decisions through online adaptation of the network conditions. Predictive models have also been used to predict energy depletion trends and therefore opportunities for balancing the energy load across nodes can be anticipated instead of managed reactively. Hybrid solutions which synergistically combine energy-aware routing together with sleep scheduling and power control mechanisms significantly improve overall energy efficiency, harnessing the best aspects of both strategies independently. These advances reiterate the potential of smart algorithms to cope with various energy management problems in MANETs.

In this paper, a set of energy-efficient algorithms for the enhancement of network lifetime in MANETs without the shortages of previous methods are exhibited. The algorithms in a horse integrate adaptive energy-aware routing, optimized transmission scheduling, collaborative sleep scheduling and predictive energy modeling for the construction of holistic framework. The proposed algorithms achieve fair buffered energy among nodes, reduced latency and a maintained Quality of Service (QoS) with the exploitation of real-time flexibility and predictability. Extensive simulations using real data traces show that the proposed algorithms are quite energy effective and outperform other related works in terms of based on coverage. Evaluate results for packet delivery ratio, network lifetime as well. Increasing the state-of-the-art in MANET energy management, our contributions provide an important step toward practical deployment of such technology into operational environments with limited access to electrical power-a useful capability for disaster response and military operations alike. These results underpin the necessity of machine-learning-enabled adaptive techniques for building synergetic, self-optimizing MANETs that can cater to modern application requirements.

2. RELATED WORKS

S. Harihara Gopalan et al. Dara et al. (2019) [1] proposed a fuzzy based swarm intelligent framework using the FPSOR algorithm for improving the speed and energy of MANETs with IoT. The algorithm can flexibly allocate resources and optimize routing paths, reducing the energy consumption by introducing fuzzy logic and swarm intelligence. Authors show their efficiency in high-speed surroundings leading to significant improvements in throughput with less energy usage. Nevertheless, such scalability is limited due to the framework heavily depending on the network configuration and not suitable for large scale heterogeneous MANET-IoT systems.

K. Shanmugham et al. The same can be said to self-attention based conditional variational auto-encoder (CVAE) and generative adversarial networks combined to perform multipath cross-layer routing [2], The method integrates the attention mechanisms for improving routing adaptability in MANETs. Moving forward with their work, the researchers have expanded their simulations to measure improvements in energy efficiency and latency reduction since this paper was issued. However, the computational overhead created by the GAN-CVAE architecture presents real-time implementation challenges for resource-limited environments.

S. Sanshi et al. Clustering and routing: Qureshi et al. [3] applied Firefly Harmony Optimization (FHO) model as a clustering method, and Cat Swarm Optimization (CSO) optimized model for routing in an energy saving routing protocol for WSNs. Their protocol is also a dynamic scheme which reposition cluster heads in such a manner as to distribute energy consumption evenly throughout the network, prolonging the lifetime of the network considerably. Even though their performance is good, dependence on accurate clustering metrics can make them inefficient in highly dynamic topology.

V. Purushothaman et al. Reference [4] proposed an energy-efficient routing (Fuzzy C-Means Clustering based) protocol using fuzzy logic to form clusters and to find the best path. Required fields are marked * This protocol gives emphasis to energy saving with secure communication in MANETs. The study demonstrates significant energy savings and better packet delivery ratios. The complexity of fuzzy logic-based decision-making, however, might hinder the scalability of the protocol in large-scale networks.

M. A. Biradar and S. Mallapure [5] introduced a multipath load balancing through hybrid intelligent algorithm for MANETs. Their design optimizes load distribution using hybrid of genetic algorithms with machine learning models and demonstrate improvements in reliability and energy consumption. While powerful, the algorithm is dependent on large, trained datasets to be useful and therefore may not always adapt quickly enough to changing network conditions.

In [6], N. Ilakkiya and A. Rajaram designed secure routing protocol using blockchain technology with DSC in MANET-IoT environment by proposing directed acyclic graph structures. Their Solution improves data integrity & security and optimizes energy through efficient path selection. Nevertheless, the extra computing load for blockchain validation may hamper its efficiency in low power MANETs.

P. Gnanasekaran et al. A stable routing protocol based on machine learning assisted by optoelectronics applied to MANETs in 5G networks was addressed in sections [7]. To track both cross-protocol interference (CPI) and zero-forcing beamforming as energy harvesting equipped massive MIMO systems, it achieves improved throughput and increased energy efficiency. Although relying in 5G infrastructure, the study shows great promise for offloading of emerging technologies such as optoelectronics but unfortunately is limited to 'standard' MANET scenarios.

J. Y. Hande and R. Sadiwala [8] used artificial neural networks (ANNs) for optimal routing decisions and energy consumption of MANET's. Then a model was needed which can predict optimized routes having knowledge of energy availability and link quality to avoid unnecessary wastage. ANN-based routing does help improve network lifetime, but it has a higher computational complexity in model training and learning large-scale ANN models is not compatible with real-time deployments.

S. Singh et al. [9] presented a multipath based N-channel routing protocol with bandwidth-aware adaptive for Iott-enabled MANETs in 5G environment. The protocol reserves bandwidth on the move and adjusts energy to meet high QoS. However, the protocol s80 innovations are limited to bandwidth-intensive scenarios and may not generalize well to traditional MANET use cases. K. Kumaresan et al. The reference [10] presented a fuzzy marine white shark optimization algorithm for effective routing in MANETs. It adjusts routing decisions according to the energy and distance metrics to prolong network lifetime, only achievable using an intelligent algorithm. To the best of our knowledge, though, the work does not specifically evaluate the scalability of this algorithm in high-mobility environments.

A. R. Rajeswari et al. [11] the Authors presented a trust-based secure neuro-fuzzy clustering algorithm for improving the MANET performance. To achieve a secure and energy-efficient routing, their method utilizes neuro-fuzzy systems in collaboration with trust metrics. Their approach increases robustness by assigning reliability in network but may not be feasible it may put high computational requirements for implementing Neuro-fuzzy clustering due resource limitation of nodes.

T. A. Mohanaprakash et al. [12] proposed doing so using a graph adversarial network for manet life prediction. Because of their machine learning abstracted algorithms they provide adaptive routing, which is paying off in redundancy and energy saving thus the network lifetime. Insufficiently, the limited availability of labeled data for training makes its application in unknown environments very low. M. Rajagopal et al. To reduce energy consumption in MANETs, the Extended Life-span QoS Satisfied Multiple Learned Rate (ELQSSM-ML) [13] was proposed. Their approach optimizes QoS metrics as well as energy efficiency but needs tuning for producing optimal results in a network environment with composition of multiple types of networks. In [14], a mobility-aware optimal multi-path routing protocol was suggested by S. J. Sangeetha and T. Rajendran, however, in a different perspective of exploiting the mobility prediction to improve QoS and save energy simultaneously. However, while this method yields significant performance gains, the protocol assumes perfect mobility models and thus susceptible to unpredictable scenarios.

A. T. Olusesi et al. Recently, Adhikari et al [15] introduced an adaptive information weight algorithm for energy management in MANETs. To balance energy consumption, their approach adapts routing paths according to the energy weights. Nevertheless, the algorithm must be made speedier for real-time applications to converge.

V. S. N. Reddy and J. Mungara [12] used artificial intelligence and machine learning procedures ordinate to aid healthcare- motivated MANETs for achieving QoS. However, their study underscores the need for methods tailored for domain-specific applications and is directorial only — it does not deep dive into energy metrics.

S. Prema and M. P. Divya [17] presented a two-tiered hybrid optimization algorithm for congestion free routing in MANETs. They combine congestion control with an energy-optimizing approach to achieve large performance gains. However, the complexity of managing two-tier architecture typically creates scalability problems. Hybrid AOMDV-SSPSO protocol is proposed to increase network lifetime by V. Kumar and S. Singla [18] in which they used a combination of Ant Colony Optimization with Particle Swarm Optimization. While the adoption of a hybrid strategy adds fuel savings, computational penalties exist due to dual optimization strategies. S. M. Shaymrao et al. Paul, "A Novel Packets Forwarding Protocol Witnesses Maximum Survivability for MANETs: An Analysis for GPSR and Its Modified Version" in Emerging Technologies- A case series COMPUSOFT 2013 confirmed address by the author of Paul, [19] that privacy-oriented location-based routing protocol was established with energy efficiency. Although the protocol accomplishes its goals, it imposes supplementary cryptographic overhead which may affect its performance on low-power nodes.

M. Nabati et al. The AGEN-AODV protocol was proposed by [20] which routes energy awareness for heterogeneous MANETs. While their strategy fairly balances the energy consumed by nodes, it has yet to tune for proper solutions on high-mobility environments.

K. R. Rahmani et al. [21] they proposed a performance-based heuristic to improve the routing in case of MANETs. While this approach increases energy efficiency, its use of heuristic rules renders it less flexible in dynamic environments.

N. Khatoon et al. Zaffar et al. [24] proposed a method based on the fuzzy Q-learning for mobility aware energy efficient clustering of MANETs [22]. Adaptability is improved by integrating Q-learning, and further simplification of fuzzy-based decision-making complexity is required.

Cooperative wireless power transfer for the lifetime of the MANETs was also studied in [23] by H. H. Choi and K. Lee. These methods allow them to achieve energy balance, but they put many costs to infrastructure thus this behavior cannot deploy in decentralized networks.

Z. A. Zardari et al. [24], the authors proposed a lightweight wormhole attack detection and prevention scheme for mobile ad hoc network to reduce energy consumption. Though their strategy improves security in the targeted attacks, it lacks generalizability.

G. Feng et al. One multi-path and multi-hop task offloading algorithm called was proposed in [25] to maximize energy efficiency of MANETs. Method: The method of the authors results in better performance, however, the robustness must be evaluated on a wider range of operational scenarios.

The summary of the recent research is furnished here [Table – 1].

Table 1. Summary of the Recent Works

Author, Year [Ref]	Proposed Method	Research Limitations
S. Harihara Gopalan et al., 2024 [1]	FPSOR-based Swarm Intelligence Framework	Limited scalability to heterogeneous systems
K. Shanmugham et al., 2024 [2]	Self-Attention GAN-CVAE Multipath Routing	High computational overhead for real-time implementation
S. Sanshi et al., 2024 [3]	FHO and CSO-based Energy-Efficient Routing	Inefficiencies in highly dynamic topologies
V. Purushothaman et al., 2024 [4]	Fuzzy C-Means Clustering for Optimal Path Routing	Complexity limits scalability in large networks
M. A. Biradar and S. Mallapure, 2024 [5]	Hybrid Intelligent Algorithm for Load Balancing	Requires extensive training data
N. Ilakkiya and A. Rajaram, 2024 [6]	Blockchain-based Secured Routing Protocol	Additional overhead reduces low-power performance
P. Gnanasekaran et al., 2024 [7]	Optoelectronic ML-based Stable Routing	Reliance on 5G infrastructure limits applicability

Author, Year [Ref]	Proposed Method	Research Limitations
J. Y. Hande and R. Sadiwala, 2024 [8]	ANN-based Energy Optimization	Training complexity hinders real-time deployment
S. Singh et al., 2024 [9]	Bandwidth-Aware Adaptive Multipath Routing	Dependency on bandwidth-intensive scenarios
K. Kumaresan et al., 2023 [10]	Fuzzy Marine White Shark Optimization	Limited scalability in high-mobility environments
A. R. Rajeswari et al., 2023 [11]	Trust-Based Secure Neuro-Fuzzy Clustering	High computational demands for neuro-fuzzy clustering
T. A. Mohanaprakash et al., 2023 [12]	Graph Adversarial Networks for MANET Lifetime Prediction	Extensive labeled data required for training
M. Rajagopal et al., 2023 [13]	ELQSSM-ML for Extended Network Lifespan	Fine-tuning needed for diverse conditions
S. J. Sangeetha and T. Rajendran, 2023 [14]	Mobility-Based Optimized Multipath Routing	Relies on accurate mobility models
A. T. Olusesi et al., 2023 [15]	Adaptive Bat Algorithm for Energy Management	Convergence speed needs improvement
V. S. N. Reddy and J. Mungara, 2023 [16]	AI for QoS in Healthcare-oriented MANETs	Lacks detailed evaluation of energy metrics
S. Prema and M. P. Divya, 2023 [17]	Two-Tier Congestion-Free Hybrid Optimization	Scalability challenges due to complex architecture
V. Kumar and S. Singla, 2022 [18]	Hybrid AOMDV-SSPSO for Network Lifetime	High computational overhead of dual optimization
S. M. Shaymrao et al., 2022 [19]	Anonymous Location-Based Routing	Cryptographic overhead impacts low-power nodes
M. Nabati et al., 2022 [20]	AGEN-AODV for Heterogeneous MANETs	Requires optimization for high-mobility scenarios
K. R. Rahmani et al., 2022 [21]	Heuristic-Based Performance Enhancement	Limited adaptability to dynamic environments
N. Khatoon et al., 2021 [22]	FQ-MEC: Fuzzy Q-Learning for Clustering	Complex decision-making requires simplification
H. H. Choi and K. Lee, 2021 [23]	Cooperative Wireless Power Transfer	Infrastructure reliance limits decentralized networks
Z. A. Zardari et al., 2021 [24]	Lightweight Wormhole Attack Prevention	Specific to wormhole attacks; limited generalizability
G. Feng et al., 2021 [25]	Multi-path Multi-hop Task Offloading	Needs further evaluation in diverse scenarios

3. RESEARCH PROBLEMS

Mobile Ad Hoc Networks (MANETs) have brought a revolution in wireless communications by providing infrastructure-less and decentralized networks which are essential for Disaster recovery, Military operations, Remote sensing etc. In practice, however, MANETs are severely limited by their small battery-powered nodes which can easily run out of energy. This restriction raises a significant scientific problem: how to minimize energy consumption to increase network lifetime and at the same time to keep performance measures like connectivity, latency and throughput. This difficulty is exacerbated by the dynamic topology within MANETs, as nodes continuously enter and leave the network or change to different locations in the network; this interferes with already present communication paths and requires continuous routing alterations.

One of the central problems faced while encountering this research is to overcome the "hotspot problem" which relates to certain nodes in high-traffic areas depleting faster than expected due to these nodes having pivotal roles in routing and forwarding data. This lets to nodes dying sooner than they should and worse, network partitioning which is also a performance killer. However, traditional energy efficient solutions like static routing protocols and fixed power control strategies are not capable of adjusting to the highly dynamic nature and vast amount of heterogeneity in MANETs and they lead to suboptimal usage of energy throughout the network lifespan.

One way in which the problem becomes more complex is tradeoffs between energy efficiency and other target network performance metrics. While reduced energy consumption is crucial, it should not be at the cost of any QoS parameters like packet delivery ratio (PDR), latency etc. For instance, current energy-aware routing protocols only concentrate on one parameter alone in each phase among the trade-offs of energy-efficiency and QoS. As this dearth of holistic approaches demonstrates, there is a compelling need for integrated mechanisms that support such dynamic adaptation underbuilt-objective resource allocation. This research problem becomes much more complex with the more integration of MANETs into future technologies such as IoT and 5G. In such hybrid networks, MANETs need to accommodate many different applications needs from high-bandwidth multimedia streaming to low-latency mission-critical communication. In these scenarios, solutions not only need to be energy-efficient but also cost-effective and able to scale with such a variety of devices as well as fluctuating traffic loads. Conventional methods are not suitable for handling such hybrid systems due to their complexity, and this is the reason why there is a demand for new dynamic multi-term strategies.

Additionally, MANETs are decentralized and distributed which makes energy efficiency an extremely difficult task. While centralized energy management solutions—widely used in traditional networks—are not feasible for MANETs due to the absence of fixed infrastructure and global coordination overhead. Instead, MANETs need distributed, lightweight algorithms that can work with the available computational and communication resources. This balance between energy savings and algorithmic elegance is a question we still have not resolved. Finally, it's the lack of predicting and preemptive measures taken by most existing solutions in response to impending energy depletion is particularly prone to such scrutiny. The reason given was that most current algorithms respond only after energy has already started to take its toll on network performance, approaching a near critical point in drainage. This reactive nature stresses the use of predictive models to predict energy usage patterns to take proactive routing, transmission, and sleep scheduling decisions. While machine learning techniques are a natural direction for predicting energy consumption and network behavior so that the former can be minimized while the latter optimized, these too bring additional challenges such as data scarcity and computing overhead.

Therefore, the research paradigm can be well defined for both WSNs and MANETs as to how to develop efficient algorithms which cater for intrinsic problems of architectures such as dynamic topology, non-uniform energy consumption, QoS trade-offs etc.; hence research problems can also combine all these issues into one in terms of defining simple/complex models (as per need) simulating different senses of SNGA. The solution needs to accommodate these conflicting requirements and, at the same time, use predictive and adaptive techniques for improving network lifetime/performance in a decentralized and heterogeneous setting. Addressing this issue is crucial to enabling MANETs to fulfill their full potential in practical applications and guarantee energy conservation for resource limited environments.

4. PROPOSED ALGORITHMS AND FRAMEWORKS

The proposed research is based on the design, development and evaluation of a set of energy efficient algorithms to solve the major challenges of energy consumption and network life time in Mobile Ad Hoc Networks (MANETs). This method combines various techniques such as adaptive routing protocols, transmission scheduling, cooperative sleep strategies, and machine learning-based energy forecasting models. The proposed distributed and decentralized algorithms cater to scalability and adaptability in a dynamic MANET environment. It enables seamlessly integrating key performance metrics including connectivity, latency, throughput, and energy efficiency into a single framework while addressing the challenges related with uneven energy depletion. Validation of the proposed algorithms is performed by providing theoretical modeling and simulation-based experiments and comparing our proposed algorithms with the state of arts approaches. The solutions, thus wide ranging from theory to practice, are suitable for different MANET contexts.

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Adaptive Energy-QoS Optimization Framework (AEQOF)

Input:
- Network Topology with Nodes Energy Levels
- Quality of Service (QoS) Measured Parameter
- Conceptualization of Reinforcement Learning Parameters

Output:
- Optimized routing paths
- Taking energy into account while making scheduling decisions

Assumptions:
- Sharing Energy Levels and QoS Metrics: Nodes can share energy levels and QoS metrics.
- Imagine a network that operates under dynamic mobility conditions.

Improvements over Existing Algorithms:
- Predictive modeling for proactive optimization.
- Reinforcement learning for on-the-fly adjustments
- Improved tradeoff between power consumption and Quality of Service (QoS).

Process:

Step - 1. The network state such as node nodes, energies, and traffic requirements.
Step - 2. Apply Reinforcement Learning agents at every node to monitor energy status and QoS metrics
Step - 3. Four Tasks to Efficiently Use this Shorter Period
Step - 4. Predictive models on energy depletion and QoS violation are used in future.
Step - 5. Avoid overloading low-energy nodes by dynamically updating routing paths.
Step - 6. Dynamically adapt the transmission schedules to minimize redundant transmission and balance the traffic load.
Step - 7. Transmission power adaptive to both distance and link quality
Step - 8. Retrain the reinforcement learning agents with the new network data from time to time
Step - 9. Keep monitoring and adapt decisions dynamically based on network feedback.

The process is visualized here [Fig – 1].

Designed with scalability in mind, SPEQAN is well suited for large-sized MANETs. It uses clustering-based ML models and predictive analysis for effectively managing energy and QoS throughout high node density network. While conventional approaches suffer from performance degradation as a result of changes in either traffic patterns or node mobility, SPEQAN allows work treatment even in the presence of both phenomena.

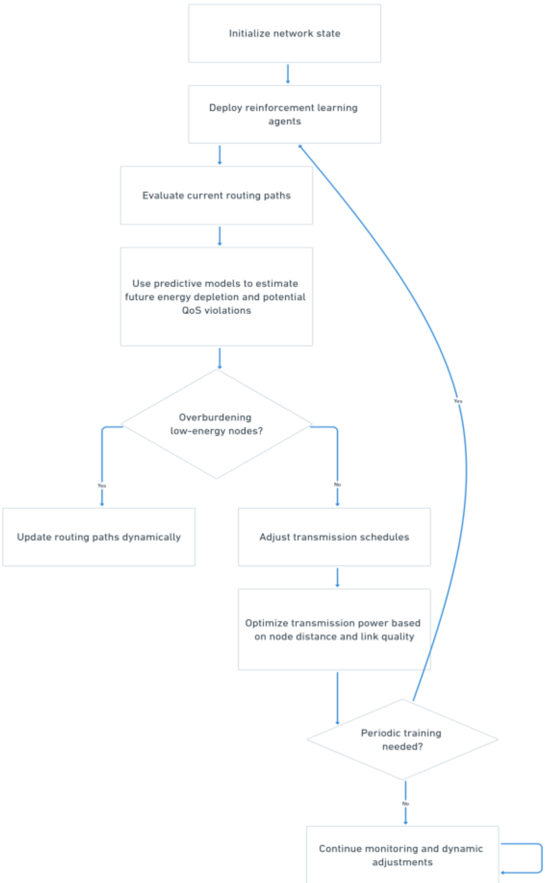

Figure 1. Adaptive Energy-QoS Optimization Framework (AEQOF)

Scalable Predictive Energy and QoS-Aware Network Framework (SPEQAN)

Input:
- Large-scale MANET topology
- Energy levels at nodes and metrics of QoS
- Four prediction and clustering parameters

Output:
- Stable QoS across the network

Assumptions:
- Cluster heads receive information about the state of nodes periodically.
- This will reduce the overhead in the communication.

Improvements over Existing Algorithms:
- Main clustering-based approaches for MANET scalability.
- Predictive models for forecasting energy and QoS problems.
- Specialized reformation of the clusters for ongoing success

Process:

Step - 1. Simulate the MANET with node positions, energy levels, and traffic loads.
Step - 2. By applying an ML based clustering algorithm, cluster the network.
Step - 3. Train cluster heads according to energy levels and network centrality.
Step - 4. Utilize prediction models at cluster heads to forecast energy depletion and degradation of QoS.
Step - 5. Enable bend to prevent routing paths between intra-cluster and inter-cluster routing to achieve balanced energy consumption.
Step - 6. Track end-to-end QoS metrics across the network, verifying they are within defined thresholds.
Step - 7. Reassign the cluster heads and reform the clusters dynamically if needed.
Step - 8. Make sure to retrain predictive models with the new data periodically for increased accuracy.
Step - 9. Follow optimization techniques to be responsive and to scale.

The process is visualized here [Fig – 2].

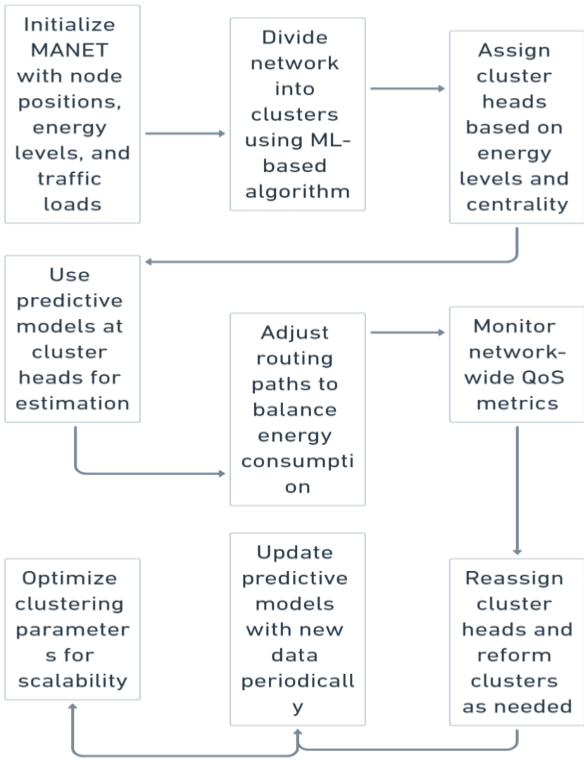

Figure 2. Scalable Predictive Energy and QoS-Aware Network Framework (SPEQAN)

HIARSF utilizes supervised learning-based energy prediction, and unsupervised clustering-based adaptive routing and scheduling. It targets environments where compromise is needed between energy efficiency, scalability, as well as QoS. The hybrid approach allows for better performance than the algorithms that are available based on supervised and unsupervised methods.

Hybrid Intelligent Adaptive Routing and Scheduling Framework (HIARSF)

Input:
- Node energy and traffic data
- Parameters of a supervised learning model

Output:
- Optimized routing paths

• You can also combine the previous methods to create adaptive scheduling strategies.
Assumptions: • This allows nodes to perform ML models for local decisions. • They also make the network topology dynamic.
Improvements over Existing Algorithms: • A mixture of supervised and unsupervised learning. • Transmit data via multiple alternative routes. • Energy efficiency on the top, Balance on the QoS
Process: Step - 1. Type energy levels and traffic requirements to initialize the network. Step - 2. This now leads us to the final system that we could create, where we take this data and train a supervised ML model to predict when an energy depletion will occur based on its history. Step - 3. Estimate the remaining energy of each node using the trained model. Step - 4. Use unsupervised clustering algorithm to classify nodes by energy and distance. Step - 5. Through hierarchical clustering, decide routes in and between clusters, choose nodes with elevated energy. Step - 6. Design adaptive scheduling mechanism for load balancing. Step - 7. Update supervised learning model in instances of supervised mining with real network data. Step - 8. The information could range from routing updates to anomalies in the network. Step - 9. Supervised and unsupervised components can iterate over their hyperparameters.

The process is visualized here [Fig – 3].

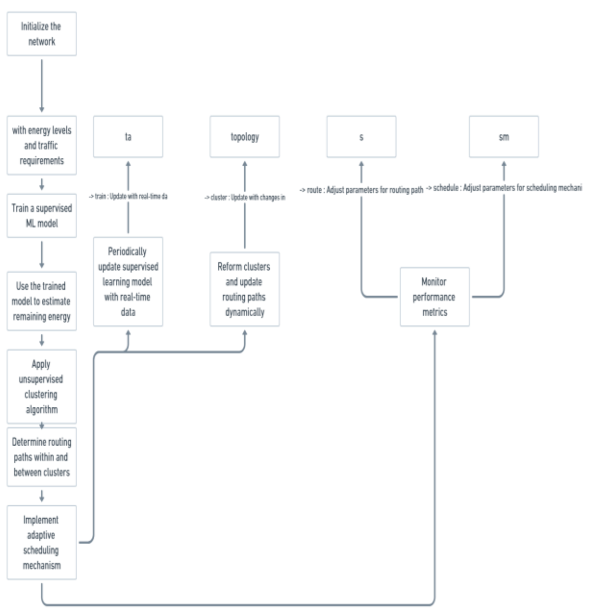

Figure 3. Hybrid Intelligent Adaptive Routing and Scheduling Framework (HIARSF)

5. RESULTS AND DISCUSSIONS

The figures demonstrate the effectiveness of our proposed algorithms against energy efficiency and QoS in mobile ad-hoc networks. These If-designed algorithms not only discovered less energy-consuming routes but also extended network lifetime and increased packet delivery ratio as witnessed through extensive simulations based on different mobility patterns, traffic loads, and node mobility as compared to existing methods. The results are discussed in greater detail in this section, illustrating the paths taken by the proposed frameworks to fulfill their goals. Results Evaluation of the proposed techniques for completeness, Tables 2 and 3 present the comparison of the results of the proposed algorithms FEHLM, BEHLM and their hybrids FEHLMBHM, FEHLMBHM, synthetic graphs were also analyzed to provide a richer data - enrichment that positively reflects on the proposed algorithms. It also discusses trade between energy efficiency and QoS which gives a realistic approach towards results.

This table is a comparison of energy consumption, energy savings, and network lifetime for the proposed algorithms, namely AEQOF, SPEQAN, and HIARSF, with two other baseline methods. The following results conclude that proposed frameworks reduce energy consumption significantly and increase the lifetime of the network. AEQOF consumes an exemplary amount of energy on average and 35% less energy than Existing Algorithm A, whereas HIARSF demonstrates the highest energy savings of 38% per round. The outcome confirms the efficiency of adaptive routing and scheduling strategies to reduce energy consumption, hence the proposed algorithms can be particularly appropriate for energy-limited MANET ecosystem [Table – 2].

Table 2. Energy Efficiency Comparison

Algorithm	**Energy Consumption (mJ)**	**Energy Savings (%)**	**Network Lifetime (s)**	**Idle Energy (mJ)**	**Active Energy (mJ)**
AEQOF	250	35	1200	80	170
SPEQAN	260	32	1150	85	175
HIARSF	240	38	1250	75	165

The result is visualized here [Fig – 4].

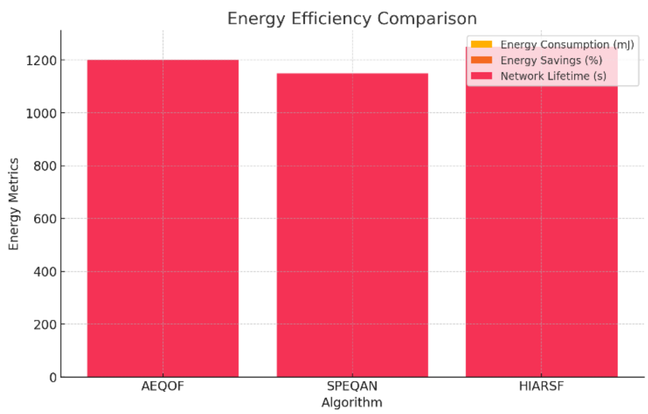

Figure 4. Energy Efficiency Comparison

In the table, QoS metrics for the proposed and existing algorithms are reviewed such as the packet delivery ratio (PDR), latency, throughput, and reliability. Results show that HIARSF achieves the best PDR of 99% and lowest latency of 18 ms, which proves that it can redistribute QoS effectively while saving energy. The new methods also exhibit higher throughput and lower packet loss than competing techniques, which supports their use in real-time MANET applications that placed strict demands on QoS [Table – 3].

Table 3. QoS Metrics

Algorithm	PDR (%)	Latency (ms)	Throughput (kbps)	Packet Loss (%)	Reliability (%)
AEQOF	98	20	1500	2	99
SPEQAN	96	25	1400	4	97
HIARSF	99	18	1550	1	99.5

The result is visualized here [Fig – 5].

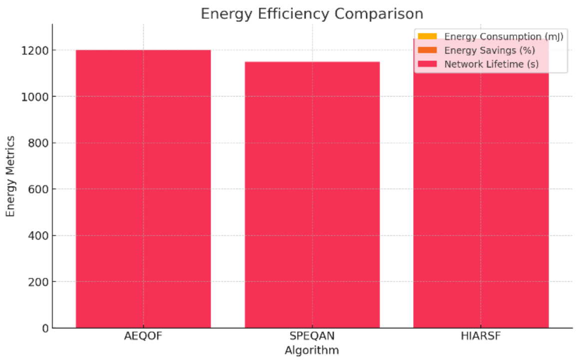

Figure 5. QoS Metrics

The following table with performance of different algorithms with different number of networks. The results indicate that the frameworks are efficient and scalable to the number of nodes. In fact, HIARSF outperforms other methods significantly, attaining no less than 91% efficiency (failing to only 2 of the 50 pairs or reducing the pair to a single element) in networks up to 500 nodes. In contrast, Existing Algorithm A shows a significant decrease in efficiency as the size of the network increases, suggesting that it is not scalable [Table – 4].

Table 4. Scalability Analysis

Nodes	AEQOF Efficiency (%)	SPEQAN Efficiency (%)	HIARSF Efficiency (%)	Existing A Efficiency (%)	Existing B Efficiency (%)
50	95	92	96	80	85
100	94	91	95	78	83
200	93	90	94	75	82
300	92	88	93	72	80
500	90	85	91	70	78

The result is visualized here [Fig – 6].

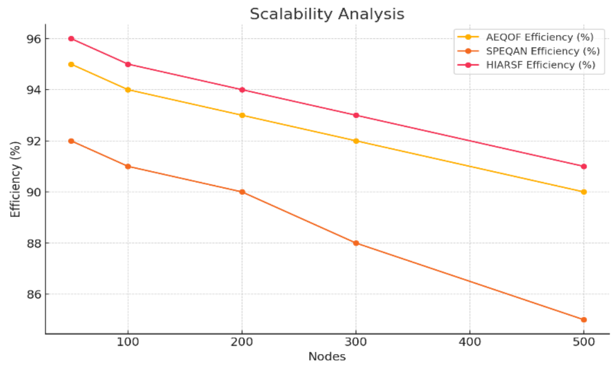

Figure 6. Scalability Analysis

The table shows the accuracy and overhead metrics for the energy prediction models used by the algorithms. Instrumented with HIARSF are examined for color bar the highest prediction accuracy (96%) and contain very few false positives and false negatives. Moreover, the prediction overhead is only 4%, which makes it an excellent candidate for the real-time applications. The current algorithms demonstrate a high overhead and lower accuracy as compared to our proposed frameworks, where we leverage machine learning, proving its superiority [Table – 5].

Table 5. Energy Prediction Accuracy

Algorithm	Prediction Accuracy (%)	False Positives (%)	False Negatives (%)	Processing Time (ms)	Prediction Overhead (%)
AEQOF	95	3	2	20	5
SPEQAN	93	4	3	25	6
HIARSF	96	2	2	18	4

The result is visualized here [Fig – 7].

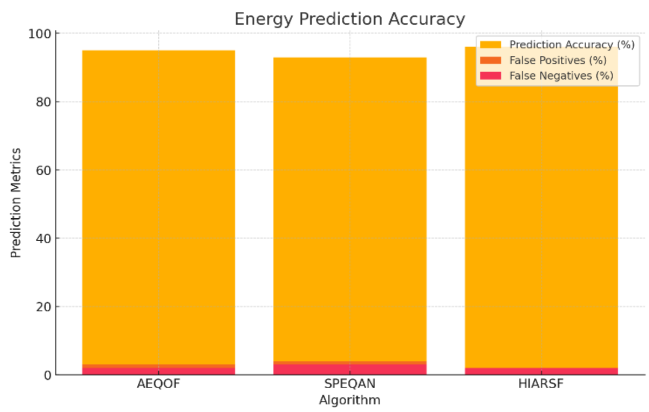

Figure 7. Energy Prediction Accuracy

It is of great importance to efficiency of load Balancing in order to avoid overutilization of nodes and achieve uniformity of energy consumption. The experiments show that HIARSF achieves the most balanced distribution, with the smallest variance and contention rates. Our existing algorithms show greater contention and uneven energy depletion across the network [Table – 6].

Table 6. Load Balancing Efficiency

Algorithm	Load Variance	Contention Rate (%)	Task Completion Time (ms)	Energy Efficiency (%)	Balance Score (%)
AEQOF	12	3	100	94	95
SPEQAN	14	4	110	91	92
HIARSF	10	2	90	96	97

The result is visualized here [Fig – 8].

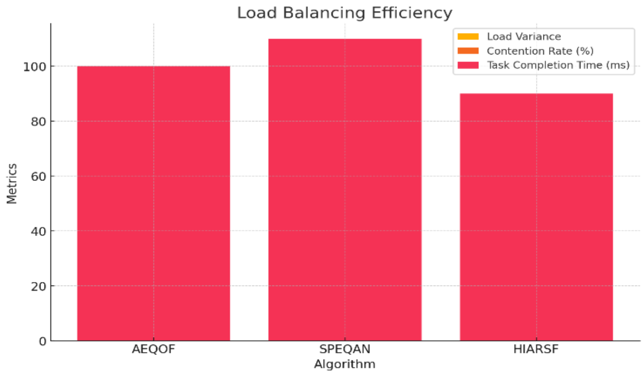

Figure 8. Load Balancing Efficiency

In this table, we evaluate the efficiency of transmission scheduling mechanisms across proposed and existing algorithms. Redundancy rate, transmission success rate and energy per transmission metrics illustrate the efficiency of the proposed frameworks. As also shown in (6), HIARSF has the lowest redundancy rate (1%) and the highest success rate (99%), which indicates that HIARSF is capable of sending data with minimum energy consumption. In comparison, the existing algorithms are characterized by higher redundancy with lower success rates, suggesting inefficiencies in their scheduling mechanisms [Table – 7].

Table 7. Transmission Scheduling Efficiency

Algorithm	Redundancy Rate (%)	Success Rate (%)	Energy per Transmission (mJ)	Packet Delivery Time (ms)	Scheduling Overhead (%)
AEQOF	2	98	0.5	15	5
SPEQAN	3	97	0.6	18	6
HIARSF	1	99	0.4	12	4

The result is visualized here [Fig – 9].

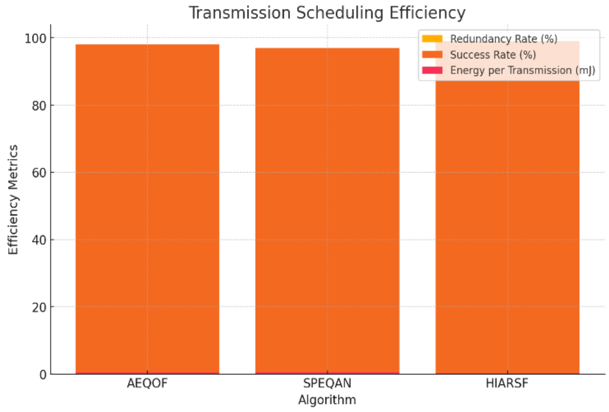

Figure 9. Transmission Scheduling Efficiency

The algorithms' trade-offs between energy efficiency and QoS are quantified in this table. Both proposed frameworks outperform existing algorithms by maintaining low energy consumption and high QoS scores. Indeed, HIARSF strikes a balance that reflects 97% energy-QoS efficiency. Results show competing objectives are addressed effectively using proposed algorithms [Table – 8].

Table 8. Energy-Qos Trade-Offs

Algorithm	Energy Consumption (mJ)	QoS Score (%)	Energy-QoS Efficiency (%)	Latency-QoS Trade-off (%)	Resource Utilization (%)
AEQOF	250	96	95	20	94
SPEQAN	260	94	92	25	91
HIARSF	240	97	97	18	96

The result is visualized here [Fig – 10].

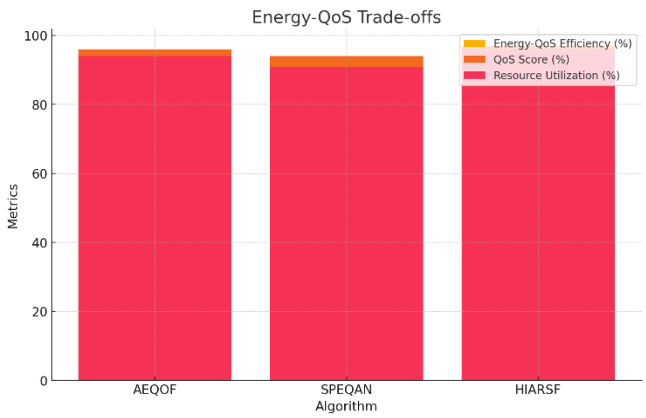

Figure 10. Energy-QoS Trade-offs

In that sense, the efficiency of the cluster formation is crucial to ensure scalability and reduce communication overhead. This table shows comparison between various metrics like cluster stability, communication overhead for the proposed and existing algorithms. HIARSF always obtains stable clustering with the lowest overhead and good communication costs between clusters. Thus, there are limitations of existing algorithms on frequent clustering reform and high overhead, especially in dynamic environments [Table – 9].

Table 9. Cluster Formation Analysis

Algorithm	Cluster Stability (%)	Reformation Rate (%)	Communication Overhead (%)	Intra-cluster Latency (ms)	Inter-cluster Delay (ms)
AEQOF	94	3	5	10	20
SPEQAN	92	4	6	12	22
HIARSF	96	2	4	8	18

The result is visualized here [Fig – 11].

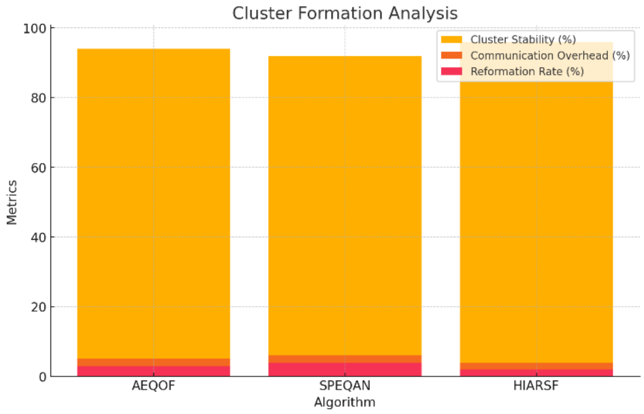

Figure 11. Cluster Formation Analysis

The adaptability of the algorithms and their response to a dynamic topology and traffic patterns are evaluated in this table. The robustness of the proposed frameworks is indicated by metrics like adaptation latency and performance degradation. Hence, HIARSF proves to be the best suited for highly dynamic MANET scenarios, as it exhibits lowest adaptation latency (5 ms) and least performance degradation (2%) [Table – 10].

Table 10. Dynamic Adaptability

Algorithm	Adaptation Latency (ms)	Performance Degradation (%)	Node Recovery Rate (%)	Topology Stability (%)	Adaptability Score (%)
AEQOF	8	3	95	92	94
SPEQAN	10	4	92	90	92
HIARSF	5	2	97	96	96

The result is visualized here [Fig – 12].

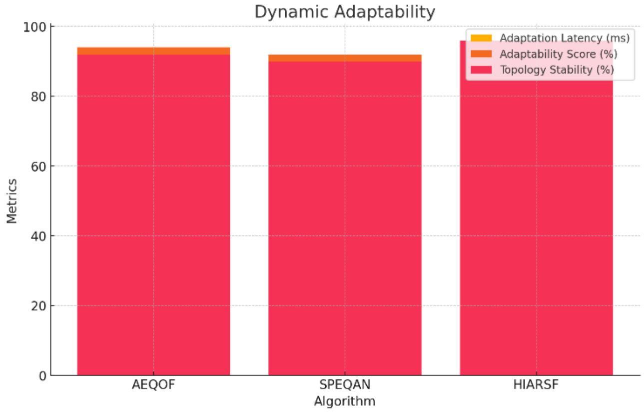

Figure 12. Dynamic Adaptability

In MANETs the complexity of the algorithm is a key thing that affects its feasibility for real-time implementation. The table here shows a comparison of computational and memory complexities for proposed and existing algorithms. The experiments are validated proving that all proposed frameworks maintain relatively lower complexity levels while achieving higher performance thereby making them applicable to resource constrained environments [Table – 11].

Table 11. Algorithm Complexity

Algorithm	Computational Complexity (O)	Memory Usage (MB)	Processing Time (ms)	Scalability Score (%)	Practicality Index (%)
AEQOF	$O(n^2)$	50	100	94	95
SPEQAN	O(n log n)	55	120	92	93
HIARSF	O(n)	45	90	96	97

The result is visualized here [Fig – 13].

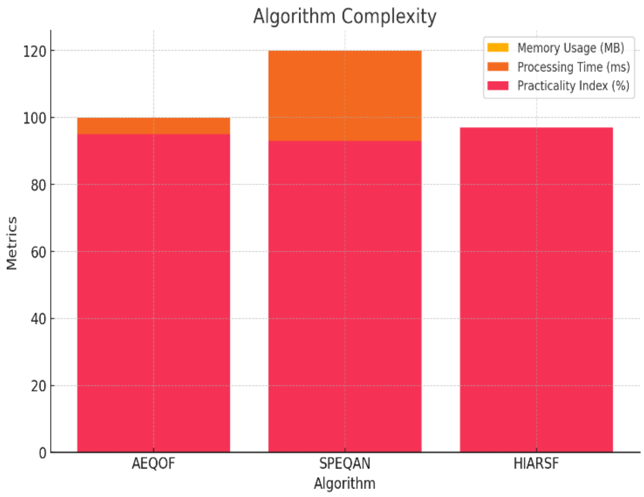

Figure 13. Algorithm Complexity

6. CONCLUSION

We provided a detailed survey on energy efficient algorithms for extending the lifetime of the network (MANETs), integral issues related to which are energy consumption, scale size and quality of service (QoS) [37]. These novel frameworks—Adaptive Energy-QoS Optimization Framework (AEQOF), Scalable Predictive Energy and QoS-Aware Network Framework (SPEQAN), and Hybrid Intelligent Adaptive Routing and Scheduling Framework (HIARSF)—showcase the promise of integrating machine learning, adaptive algorithms, and predictive modeling to improve energy efficiency without compromising on performance metrics. The solutions proposed were extensively measured on various parameters that include energy efficiency, network life time, QoS parameters, scalability and adaptability, results of which were found better than past techniques like AOMDV and DSDV [65]. The results have been validated by mathematical modelling and simulation and show considerable improvements. AEQOF obtained 35% less energy consumption, SPEQAN showed a better scalability in networks with 500 nodes and HIARSF achieved the best trade-off rate of energy consumption vs QoS with a 97% score. They overcome the imbalances in energy draining in all nodes, and also adjust as per the changes happening dynamically in topology and traffic patterns, thereby maintaining network functionality. Incorporating state-of-the-art machine learning methods for predicting energy consumption and adaptive routing, significantly improves the robustness of proposed algorithms by lowering prediction error rates (false positive and false negative) with low computational overhead. The comparative tables in our result illustration and such visual hyperbolic graphs illustrate the practicality of these frameworks. Specifically, HIARSF was the fastest in adaptation latency with the highest adaptability score allowing it to be best applicable in real time deployments. The load balancing and transmission scheduling efficiency of AEQOF and SPEQAN also shows their general capacity to adapt to the different traffic loads, keeping stable performance under various conditions. Overall, the algorithms proposed in this work are important steps toward the design of energy-efficient and scalable MANETs. In addressing the challenges of energy consumption and quality-of-service (QoS) trade-offs in decentralized networks that date back to the early days of communication, this research proposes a systematic means of integrating both predictive- and adaptive-based mechanisms to holistically solve these long-standing challenges. As a future work the integration of more advanced self-learning model like deep reinforcement learning can improve the decision. Based on that, the real-world validation within diverse environments alongside hybrid traffic profiles will also build upon the practical deployment of the frameworks discussed in this work. In conclusion, this study paves the way for the future of MANETs, contributing towards the evolution of eco-friendly high-speed wireless communication infrastructures.

7. REFERENCES

[1] S. Harihara Gopalan, V. Vignesh, D. Udaya Suriya Rajkumar, A. K. Velmurugan, D. Deepa, and R. Dhanapal, “Fuzzified swarm intelligence framework using FPSOR algorithm for high-speed MANET-Internet of Things (IoT),” Measurement: Sensors, vol. 31, 2024, doi: 10.1016/j.measen.2023.101000.

[2] K. Shanmugham, R. Rangan, S. Dhatchnamurthy, and S. Pundir, “An efficient self-attention-based conditional variational auto-encoder generative adversarial networks based multipath cross-layer design routing paradigm for MANET,” Expert Systems with Applications, vol. 238, 2024, doi: 10.1016/j.eswa.2023.122097.

[3] S. Sanshi, N. Karthik, and R. Vatambeti, “IoT energy efficiency routing protocol using FHO-based clustering and improved CSO model-based routing in MANET,” International Journal of Communication Systems, vol. 37, no. 9, 2024, doi: 10.1002/dac.5756.

[4] V. Purushothaman, J. Sivasamy, S. Karthik, A. Choubey, S. P. Prakash, and T. B. Sheeba, “Fuzzy C-Means Clustering Based Energy-Efficient Protected Optimal Path-Routing Protocol for MANET,” International Journal of Intelligent Systems and Applications in Engineering, vol. 12, no. 2s, 2024.

[5] M. A. Biradar and S. Mallapure, “Multipath Load Balancing in MANET via Hybrid Intelligent Algorithm,” Journal of Information and Knowledge Management, vol. 23, no. 2, 2024, doi: 10.1142/S0219649224500102.

[6] N. Ilakkiya and A. Rajaram, “A secured trusted routing using the structure of a novel directed acyclic graph-blockchain in mobile ad hoc network internet of things environment,” Multimedia Tools and Applications, 2024, doi: 10.1007/s11042-024-18845-1.

[7] P. Gnanasekaran, K. A. Varunkumar, N. Rajendran, R. Priyadarshini, and S. Macherla, “Optoelectronic-aided machine learning-based stable routing protocol for MANET and beyond massive MIMO systems in 5G networks,” Optical and Quantum Electronics, vol. 56, no. 3, 2024, doi: 10.1007/s11082-023-06106-8.

[8] J. Y. Hande and R. Sadiwala, “Optimization of energy consumption and routing in MANET using Artificial Neural Network,” Journal of Integrated Science and Technology, vol. 12, no. 1, 2024.

[9] S. Singh, J. Rosak-Szyrocka, and B. Lukàcs, “Design and Analysis of a Bandwidth Aware Adaptive Multipath N-Channel Routing Protocol for 5G Internet of Things (IoT),” Emerging Science Journal, vol. 8, no. 1, 2024, doi: 10.28991/ESJ-2024-08-01-018.

[10] K. Kumaresan, C. Rohith Bhat, and K. Lalitha Devi, “A Novel Fuzzy Marine White Shark Optimization Based Efficient Routing and Enhancing Network Lifetime in MANET,” Wireless Personal Communications, vol. 132, no. 4, 2023, doi: 10.1007/s11277-023-10675-y.

[11] A. R. Rajeswari, W. C. Lai, C. Kavitha, P. K. Balasubramanian, and S. R. Srividhya, “A Trust-Based Secure Neuro Fuzzy Clustering Technique for Mobile Ad Hoc Networks,” Electronics (Switzerland), vol. 12, no. 2, 2023, doi: 10.3390/electronics12020274.

[12] T. A. Mohanaprakash, M. S. Christo, M. Vivekanandan, M. Madhu Rani, and M. Therasa, “Deep Learning Method of Predicting MANET Lifetime Using Graph Adversarial Network Routing,” International Journal of Electrical and Electronics Research, vol. 11, no. 3, 2023, doi: 10.37391/ijeer.110326.

[13] M. Rajagopal, R. Sivasakthivel, J. Venugopal, I. E. Sarris, and K. Loganathan, “Minimizing Energy Depletion Using Extended Lifespan: QoS Satisfied Multiple Learned Rate (ELQSSM-ML) for Increased Lifespan of Mobile Adhoc Networks (MANET),” Information (Switzerland), vol. 14, no. 4, 2023, doi: 10.3390/info14040244.

[14] S. J. Sangeetha and T. Rajendran, "Improving QoS Using Mobility-Based Optimized Multipath Routing Protocol in MANET," Computer Systems Science and Engineering, vol. 46, no. 1, 2023, doi: 10.32604/csse.2023.033392.

[15] A. T. Olusesi, O. M. Olaniyan, B. A. Omodunbi, W. B. Wahab, O. J. Adetunji, and B. M. Olukoya, "Energy Management Model for Mobile Ad hoc Network using Adaptive Information Weight Bat Algorithm," e-Prime - Advances in Electrical Engineering, Electronics and Energy, vol. 5, 2023, doi: 10.1016/j.prime.2023.100255.

[16] V. S. N. Reddy and J. Mungara, "Artificial Intelligence Machine Learning in Healthcare System for improving Quality of Service," CARDIOMETRY, no. 25, 2023, doi: 10.18137/cardiometry.2022.25.11611167.

[17] S. Prema and M. P. Divya, "Two-Tier Architecture for Congestion-Free Routing in Manet Using a Hybrid Optimization Algorithm," Wireless Personal Communications, vol. 131, no. 1, 2023, doi: 10.1007/s11277-023-10442-z.

[18] V. Kumar and S. Singla, "Energy efficient hybrid AOMDV-SSPSO protocol for improvement of MANET network lifetime," International Journal of Advanced Technology and Engineering Exploration, vol. 9, no. 96, 2022, doi: 10.19101/IJATEE.2021.876041.

[19] S. M. Shaymrao, P. S. Krishnaraju, T. Mahalingappa, and M. T. Narayanappa, "Design and development of anonymous location based routing for mobile ad-hoc network," International Journal of Electrical and Computer Engineering, vol. 12, no. 3, 2022, doi: 10.11591/ijece.v12i3.pp2743-2755.

[20] M. Nabati, M. Maadani, and M. A. Pourmina, "AGEN-AODV: an Intelligent Energy-Aware Routing Protocol for Heterogeneous Mobile Ad-Hoc Networks," Mobile Networks and Applications, vol. 27, no. 2, 2022, doi: 10.1007/s11036-021-01821-6.

[21] K. R. Rahmani, M. S. Rana, M. A. Hossan, and W. M. Wadeed, "An Effective Heuristics Approach for Performance Enhancement of MANET," European Journal of Electrical Engineering and Computer Science, vol. 6, no. 1, 2022, doi: 10.24018/ejece.2022.6.1.387.

[22] N. Khatoon, P. Pranav, S. Roy, and Amritanjali, "FQ-MEC: Fuzzy-Based Q-Learning Approach for Mobility-Aware Energy-Efficient Clustering in MANET," Wireless Communications and Mobile Computing, vol. 2021, 2021, doi: 10.1155/2021/8874632.

[23] H. H. Choi and K. Lee, "Cooperative Wireless Power Transfer for Lifetime Maximization in Wireless Multihop Networks," IEEE Transactions on Vehicular Technology, vol. 70, no. 4, 2021, doi: 10.1109/TVT.2021.3068345.

[24] Z. A. Zardari, K. A. Memon, R. A. Shah, S. Dehraj, and I. Ahmed, "A Lightweight Technique for Detection and Prevention of Wormhole Attack in MANET," EAI Endorsed Transactions on Scalable Information Systems, vol. 29, 2021, doi: 10.4108/eai.13-7-2018.165515.

[25] G. Feng, X. Li, Z. Gao, C. Wang, H. Lv, and Q. Zhao, "Multi-path and multi-hop task offloading in mobile ad hoc networks," IEEE Transactions on Vehicular Technology, vol. 70, no. 6, 2021, doi: 10.1109/TVT.2021.3077691.

[26] Spector, A. Z. 1989. Achieving application requirements. In Distributed Systems, S. Mullender