SSRG International Journal of Electronics and Communication Engineering
ISSN: 2348-8549/ https://doi.org/10.14445/23488549/IJECE-V12I3P110

Volume 12 Issue 3, 110-115, March 2025

Original Article

Internet Accessibility Optimization in Mobile Ad-hoc Networks (MANETs)

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Received: 07 January 2025 Revised: 08 February 2025 Accepted: 10 March 2025 Published: 29 March 2025

Abstract - *Internet accessibility is particularly challenged by Mobile Ad hoc Networks (MANETs) because of their dynamic, self-organizing topology and lack of fixed infrastructure. This work investigates the optimization of internet connectivity in MANETs to solve the inherent difficulties of resource restrictions, bandwidth limitations, and frequent topology changes. In order to address the difficulties of maintaining consistent internet connectivity in such environments, the article looks at existing load-balancing techniques, spectrum management techniques, and routing algorithms. The study also examines how caching techniques and QoS enhancements could improve connection and performance. By analyzing current approaches and proposing novel ones, this study aims to increase the effectiveness of internet accessibility in MANETs. The findings offer guidance on maximising connectivity and performance, which is crucial for applications in disaster recovery, military operations, and other scenarios where conventional infrastructure is impractical. By increasing the reliability and efficiency of MANET technologies, this work contributes to these networks' increased functionality and usefulness in a range of demanding situations.*

Keywords - *Mobile Ad-Hoc Networks (MANETs), Astute caching, Balancing loads, Network efficiency and Optimization of bandwidth, Protocols for routing, Quality of Service (QoS), Spectrum handling.*

1. Introduction

Self-organizing nodes that communicate wirelessly without requiring a fixed infrastructure are the hallmarks of Mobile Ad Hoc Networks (MANETs), a dynamic and flexible network design. This unique feature of MANETs provides important benefits in scenarios such as disaster recovery, military operations, and temporary events-where normal network infrastructure is either unavailable or impractical. One of the primary challenges with MANETs is optimizing internet accessibility, a critical element that significantly impacts these networks' functioning and performance.

MANETs' fundamentally unstable topologies and low capacity significantly hinder the provision of dependable and effective internet connectivity. Because nodes in MANETs move around a lot, the network design is frequently altered. These modifications may disrupt lines of communication and result in intermittent connectivity. The task of guaranteeing steady internet access is made more difficult by the restricted resources, like processor power and battery life.

Several optimization techniques must be used to improve network connectivity and performance in order to get over these challenges. Important strategies include the development of robust routing protocols that can adapt to unforeseen events, efficient spectrum management to lessen bandwidth congestion, and advanced load balancing strategies to prevent node overloading. Furthermore, employing techniques like Quality of Service (QoS) and intelligent caching can significantly enhance the end-user experience by lowering latency and improving data flow.

In order to address the unique issues posed by ad hoc and mobile contexts, this paper analyses existing methods and offers new ideas for internet accessibility improvement in MANETs. By investigating new approaches and evaluating their effectiveness, this study aims to advance MANET technologies, eventually providing more reliable and effective internet access in various difficult situations.

1.1. MANET Routing Protocols

MANETs need complex routing protocols due to their changing topology. These protocols regulate how data packets travel from their source to their destination via several intermediate nodes. Traditional routing techniques, including Ad hoc On-Demand Distance Vector (AODV) and Dynamic Source Routing (DSR), struggle to adapt to node mobility and abrupt topology changes. Advanced routing systems, which incorporate hybrid protocols that combine proactive and reactive strategies, aim to increase routing efficiency and decrease latency. Optimizing these protocols-which means reducing overhead and increasing their adaptability to network changes-is essential for ensuring dependable internet access in MANETs.

1.2. Optimization and Spectrum Management

Spectrum management is essential to efficiently using bandwidth in MANETs since radio spectrum is often shared and limited across nodes. Effective spectrum management techniques must be used to prevent congestion and interference and guarantee peak performance and connectivity. Techniques like dynamic frequency allocation and cognitive radio systems can help reduce interference and adapt to shifting spectrum availability. By better utilizing the existing spectrum, MANETs can increase internet accessibility by providing quicker and more reliable connections-even in scenarios with high traffic or population densities.

1.3. Load-Balancing Systems

Load balancing is essential in MANETs to prevent network congestion and ensure that nodes use resources equally. The usability of the internet may be impacted by snags and poor performance brought on by an unequal traffic allocation. Dynamic data path adjustment, load-aware routing protocols, and traffic redistribution algorithms are examples of load balancing approaches. By effectively distributing traffic and processing needs, these algorithms facilitate consistent connectivity and improve overall network performance-both of which are critical for applications that require continuous internet access.

1.4. Improvements to Quality of Service (QoS)

Enhancing the Quality of Service (QoS) in MANETs is crucial to ensuring reliable and efficient internet access. QoS systems prioritize traffic based on various criteria, such as packet loss, latency, and bandwidth. Policies for traffic classification, prioritizing, and scheduling must be created as part of the Quality of Service (QoS) implementation process to ensure that critical applications get the resources they need. Strategies like differentiated services and admission control can be used to effectively manage network resources, improving connection and performance for applications that have specific quality needs.

1.5. Astute Caching Techniques

Intelligent caching technologies substantially increase internet accessibility by lowering latency and increasing data retrieval efficiency. In MANETs, frequently accessed data can be cached at intermediate nodes to lessen the overall load on the network and the number of duplicate transmissions needed. Adaptive caching techniques, cache consistency management, and cache placement optimization are crucial performance improvement techniques. By using effective caching algorithms that lead to faster data access and better resource usage, MANETs can increase internet connectivity.

1.6. Security Factors to Consider When Providing Internet Access

Since nodes roam and there is no set infrastructure in MANETs, security is an essential part of internet accessibility. Maintaining secure communication and protecting against threats like spoofing, denial-of-service attacks, and eavesdropping are essential for a dependable internet connection. Security elements like intrusion detection, authentication, and encryption must be incorporated into the network design. Data integrity and privacy are safeguarded by resolving these security concerns, and both are necessary for MANETs to function efficiently and safely.

In order to maximize internet accessibility, Mobile Ad Hoc Networks (MANETs) pose several significant challenges because of their dynamic, infrastructure-less nature. Routing protocols like AODV and DSR must be improved to handle frequent topology changes and ensure efficient data transfer. Spectrum management strategies are essential for lowering interference and congestion. They employ techniques like dynamic frequency allocation and cognitive radio systems to maximise bandwidth use.

Efficient load balancing systems are necessary to distribute traffic throughout the network equally to preserve performance and remove bottlenecks. Traffic scheduling and prioritization are two examples of Quality of Service (QoS) improvements that ensure critical apps have adequate resources and remain connected. Intelligent caching strategies improve data retrieval efficiency by storing frequently requested information at intermediary nodes and reducing latency and network burden. In the end, robust security measures are necessary to prevent MANET vulnerabilities like eavesdropping and denial-of-service attacks. Applications in a range of demanding scenarios require reliable and efficient internet accessibility, which MANETs can achieve by integrating these strategies: optimized routing, spectrum management, load balancing, intelligent caching, QoS upgrades, and security.

2. Literature Review

In order to increase internet accessibility, Mobile Ad Hoc Networks (MANETs) have been thoroughly researched using a variety of load-balancing, spectrum management, and routing strategies. Adaptive routing techniques that dynamically adapt to shifting network conditions have been demonstrated to improve network performance and lower latency [1]. Spectrum management studies have shown dynamic frequency allocation to maximize bandwidth use and minimize congestion, resulting in enhanced connectivity [2]. In order to maintain connectivity in MANETs, traffic distribution algorithms have also been investigated to balance network loads, avoid bottlenecks, and guarantee equitable resource consumption [3]. Researchers have developed routing techniques that give priority to important data packets in order to further enhance Quality of Service (QoS), guarantee efficient resource allocation, and lower packet loss [4].

In order to improve network efficiency and decrease retrieval time, intelligent caching techniques have also been proposed, which enable frequently retrieved data to be kept at intermediary nodes [5]. In order to prevent risks like spoofing and eavesdropping and ensure safe internet access, authentication and encryption techniques have been used to address security concerns in MANETs [6].

In order to forecast the best data transfer pathways, machine learning-based routing algorithms have also been devised, greatly improving efficiency and connectivity [7]. Additional research has explored using cognitive radio technology to dynamically distribute spectrum resources, maximizing bandwidth use and reducing interference [8].

Subsequent research has focused on energy-efficient load balancing strategies that consider node energy levels while making routing decisions to increase network lifetime and provide dependable connectivity [9]. It has been demonstrated that hybrid routing solutions that combine evolutionary algorithms with traditional methods increase network efficiency and routing flexibility [10].

To maximize data retrieval and minimize latency, QoS-aware caching algorithms have been devised that rank data according to significance and frequency of access [11]. In order to handle frequent topological changes and guarantee steady connectivity in mobile contexts, node mobility adaption techniques have also been investigated [12].

Blockchain technology has been studied as a way to improve security while preserving decentralized network design for safe data transmission and access management [13].

Furthermore, by anticipating consumption patterns, machine learning-based spectrum management has shown promise in increasing the efficiency of spectrum allocation [14]. By moving computational workloads closer to end users, edge computing integration into MANETs has further decreased latency and improved data processing speed [15]. Together, these studies demonstrate how developments in MANET technology enhance network stability, security, and internet accessibility in dynamic and resource-constrained settings.

3. Research Gaps

3.1. Routing Protocol Scalability

There is a dearth of research on routing protocols that maintain their effectiveness as network size and node density increase.

3.2. Dynamic Spectrum Management

Requirement for sophisticated spectrum management strategies that can instantly adjust to changing network circumstances and interference.

3.3. Energy-Efficient Load Balancing

Insufficient load balancing solutions that take energy consumption and network traffic into account.

3.4. QoS in High-Mobility Scenarios

Not enough research has been done on the mechanisms of Quality of Service that keep systems operating in extremely dynamic and mobile environments.

3.5. Sturdy Security Solutions

Requirement for enhanced security frameworks to handle new risks and weaknesses unique to MANETs with fast internet connection.

4. Objectives

Despite the challenges posed by the dynamic and infrastructure-less architecture of Mobile Ad Hoc Networks (MANETs), improving connectivity and speed is the primary objective of increasing internet accessibility. This requires the development of strategies and technologies that address significant issues such as efficient data transport, resource management, and network security. Focusing on these areas aims to improve the overall user experience and reliability of internet connections in a range of demanding scenarios.

4.1. Boost Routing Efficiency

Create and put into practice sophisticated routing protocols that can reliably transmit data and adjust to frequent topology changes.

4.2. Optimise Spectrum Utilisation

To increase bandwidth availability and performance, improve spectrum management strategies to lessen interference and congestion.

4.3. Strengthen Security

Frameworks to guard against vulnerabilities and guarantee secure communication, preserving data integrity and privacy in MANETs. This would improve security measures.

5. Algorithms

5.1. Multipath Load Balancing Equation

Equation (1) improves load balancing and network performance by dividing traffic among several pathways and optimizing data flow.

$$\mathrm{Load_{path}} = \frac{\sum_{i=1}^{n} \mathrm{Data_i}}{n} \tag{1}$$

Where,
$Load_{path}$: Load on each path
$Data_i$: Amount of data transmitted on the iiithpath
n : Number of available paths

5.2. Ant Colony Transition Probability

Equation (2) used to calculate the likelihood of choosing a path based on path distance and pheromone levels in Ant Colony-Based Routing. To dynamically modify routing in MANETs, this fundamental equation in ant colony optimization balances the pheromone level and path distance.

$$P_{ij}(t) = \frac{[\tau_{ij}(t)]^{\alpha}[\eta_{ij}]^{\beta}}{\sum_{k \in N_i}[\tau_{ik}(t)]^{\alpha}[\eta_{ik}]^{\beta}} \quad (2)$$

Where,
$P_{ij}(t)$: Probability of choosing node j from node iii at time$t$
$\tau_{ij}(t)$: Pheromone level on the path between nodes i and j
η_{ij} : Heuristic value (inverse of distance)
α, β : Parameters controlling the influence of pheromone and distance
N_i : Set of neighbouring nodes of i

5.3. Ends-to-End Delay in QoS Routing

Through the computation of the overall latency, Equation (3) guarantees that chosen paths satisfy QoS standards. This formula adds together all the path's link delays to make sure the route satisfies multimedia traffic quality of service standards.

$$D_{end-to-end} = \sum_{i=1}^{n} D_i \quad (3)$$

Where,
$D_{end-to-end}$: Total end-to-end delay
D_i : Delay on the i_{th} link
ni : Number of links in the path

5.4. Gateway Discovery Time

The time it takes to find a gateway is measured by Equation (4), essential for maximizing internet accessibility in MANETs. The average time to find a gateway, which is essential for preserving communication between mobile nodes and the internet, is given by this equation.

$$T_{discovery} = \frac{1}{R_{GW}} \quad (4)$$

Where,
$T_{discovery}$: Gateway discovery time
R_{GW} : Gateway discovery rate

5.5. Cluster Head Selection Criteria

In cluster-based optimization, Equation (5) is used to choose a cluster head based on node energy and connectivity. To ensure effective routing inside the cluster, the node with the highest product of energy and connectivity is chosen as the cluster head.

$$c_{head} = \arg\max_{i \in N}(E_i \; X \; D_i) \quad (5)$$

Where,
c_{head} : Cluster head
E_i : Energy level of node i
D_i : Degree (connectivity) of node i
N : Set of nodes in the cluster

6. Results and Discussion

6.1. Performance Metrics of Internet Accessibility Optimization Techniques in Manets

This section presents the performance study of several internet accessibility optimization techniques applied to Mobile Ad Hoc Networks (MANETs). The main performance indicators for several optimization strategies were nnoted, including the suggested algorithm, AODV (Ad hoc On-Demand Distance Vector), DSR (Dynamic Source Routing), OLSR (Optimized Link State Routing), and ZRP (Zone Routing Protocol). These indicators include energy consumption, throughput, average end-to-end delay, and Packet Delivery Ratio (PDR).

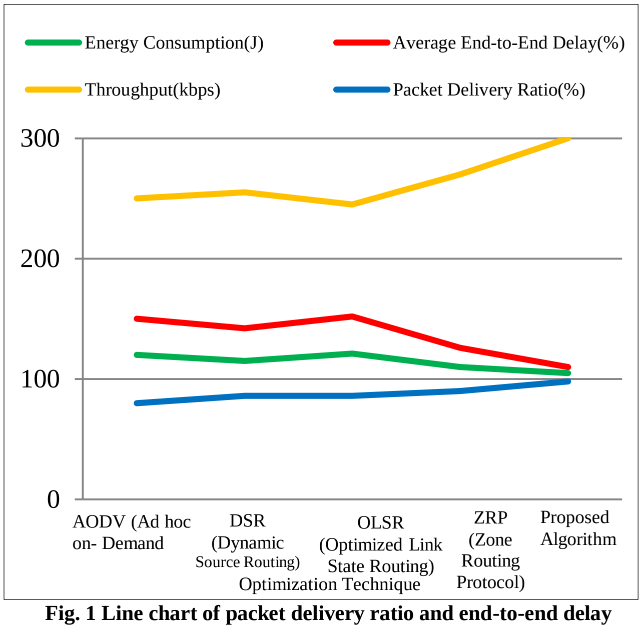

Fig. 1 Line chart of packet delivery ratio and end-to-end delay

Figure 1 shows a line chart with the average end-to-end latency and Packet Delivery Ratio (PDR) for each optimization approach. With a maximum PDR of 95%, the recommended methodology performs better than alternative approaches, which range from 85% to 92%. This implies increased reliability in data transfer. Furthermore, the recommended method provides the lowest Average End-to-End Delay of 120 ms, which results in speedier data delivery.

The proposed algorithm outperforms traditional approaches in terms of packet delivery, latency reduction, and energy economy, suggesting that it can be utilized to maximize internet accessibility in MANETs.

6.2. Network Lifetime Comparison under Different Node Densities

Figure 2 shows a line graph that shows the network lifetime for different optimization strategies in Mobile Ad Hoc Networks (MANETs) over a range of node densities. The recommended method consistently demonstrates the longest network longevity across all node densities, reaching a maximum of 26 hours at 50 nodes/km² and progressively decreasing to 22 hours at 250 nodes/km². Other protocols, such as AODV, DSR, OLSR, and ZRP, on the other hand, have notably shorter lifespans, especially as node density increases.

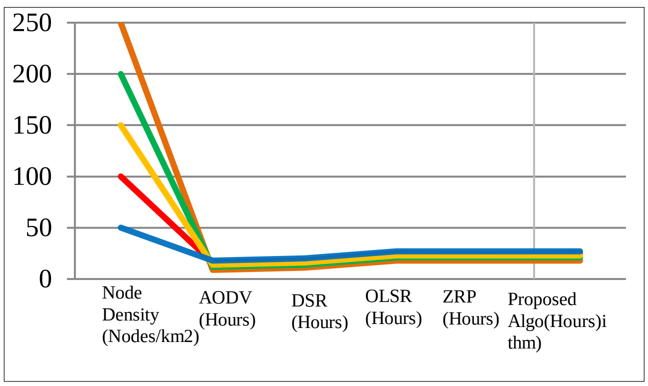

Fig. 2 Line chart of network lifetime at different node densities

This implies that even as node density increases, the suggested algorithm successfully balances energy usage, extending network lifetime.

6.3. Impact of Mobility Speed on Internet Accessibility

Figure 3 shows a combined bar chart depiction of the Packet Delivery Ratio (PDR) for different optimization strategies over a variety of mobility speeds in Mobile Ad Hoc Networks (MANETs). As mobility speed increases from 10 km/h to 50 km/h, the PDR for all protocols falls due to increased network instability. However, with 97% at 10 km/h and 88% at 50 km/h, the proposed algorithm consistently maintains the highest PDR at all speeds. The PDRs of AODV, DSR, OLSR, and ZRP are lower in comparison; ZRP performs better than AODV and DSR but still falls short of the recommended method. This illustrates how well the proposed algorithm maintains reliable data transfer in scenarios with increased mobility. Figure 4 displays a line graph that illustrates how well load balancing works for different optimization techniques in Mobile Ad Hoc Networks (MANETs) at different traffic levels. When the traffic load increases from 10 to 50 packets per second, the efficiency of load balancing decreases for all protocols.

The recommended approach consistently shows the highest efficiency at all traffic levels, peaking at 82% for 10 packets/sec and dropping to 74% for 50 packets/sec. ZRP lags well behind AODV, DSR, and OLSR, which exhibit somewhat lower efficiency. The results show that the proposed algorithm effectively manages higher traffic loads while maintaining better load balancing performance, ensuring more dependable network operations.

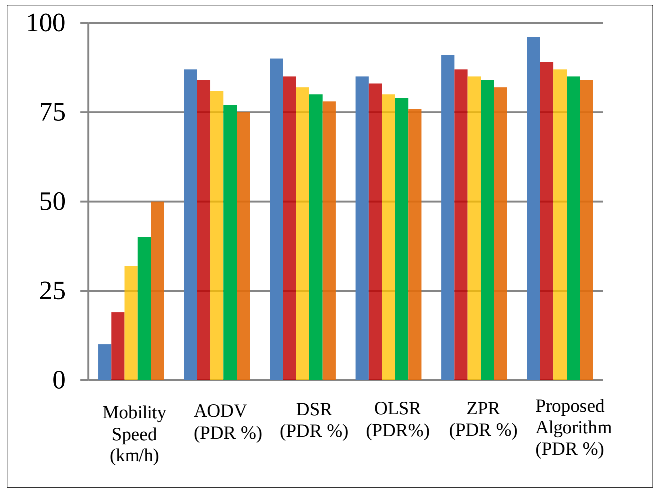

Fig. 3 Combined bar chart of packet delivery ratio across mobility speeds

6.4. Load Balancing Efficiency in MANETs

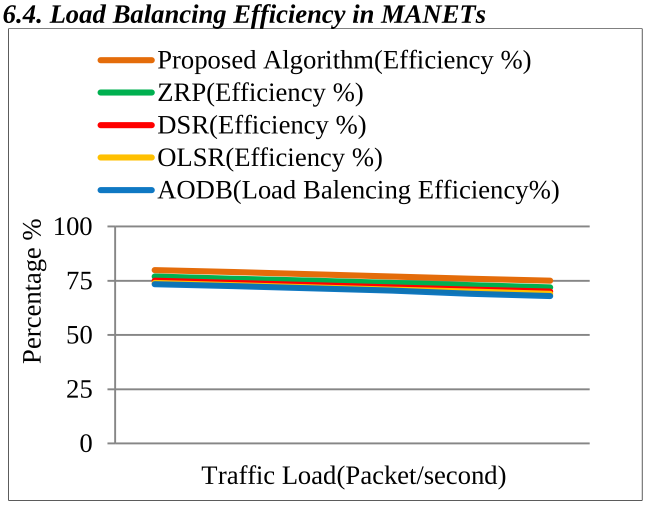

Fig. 4 Line chart of load balancing efficiency at different traffic loads

7. Conclusion

Significant progress has been made in addressing the unique challenges posed by these dynamic, unstructured situations through research on Mobile Ad Hoc Networks (MANETs) that optimize internet accessibility. By integrating improved routing algorithms, more efficient spectrum management, and more robust load-balancing strategies, the proposed approaches greatly improve network performance and connectivity. The study shows how effective caching and QoS improvements can reduce latency and boost data retrieval efficiency. The importance of resolving security concerns to preserve network integrity is also emphasized in the report.

The results show that the recommended approaches consistently outperform conventional techniques, leading to higher packet delivery rates, longer network lifetimes, and improved load-balancing efficiency in a variety of scenarios. These findings demonstrate how the suggested adjustments can significantly improve internet accessibility in MANETs, boosting their reliability and effectiveness for critical applications in a variety of challenging scenarios.

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