

Performance Evaluation of AODV and DSR Routing Protocols with Increasing Network Size in MANETs

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ABSTRACT

In mobile ad-hoc networks (MANETs), the implementation of efficient routing protocols is crucial for sustaining connectivity in environments devoid of infrastructure. This research examines the comparative effectiveness of two commonly utilized reactive routing protocols—AODV and DSR—via NS-2 simulations under increasing network size scenarios while maintaining comparable network connectivity. The focus of the analysis is on essential performance indicators such as packet delivery ratio, end-to-end delay, routing overhead, and throughput. The findings indicate that the performance of the protocols is predominantly influenced by network size and scalability effects, particularly regarding routing overhead, latency, and data delivery performance. The results highlight the importance of considering network size as a key factor when selecting routing protocols under controlled simulation conditions in MANETs. Unlike many existing studies that assume a fixed network size, this work emphasizes scalability behaviour by progressively increasing the number of nodes under uniform simulation conditions.

Keywords

Ad hoc Networks, AODV, DSR, Network Size, Scalability, Performance Evaluation.

1. INTRODUCTION

A mobile ad hoc network (MANET) is a self-coordinated wireless network that operates without a perpetual foundation, established infrastructure, or central control [1]. A MANET consists of a collection of mobile nodes, where each node functions simultaneously as both a host and a router. A Mobile Ad Hoc Network (MANET) is characterized by its lack of infrastructure, and its topology is subject to dynamic changes as a result of node mobility, necessitating ongoing route discovery and maintenance. In military convoys, where tanks, soldiers, and vehicles move rapidly through enemy territory and challenging terrain, the network topology is constantly changing. In such highly mobile environments, reactive protocols like AODV and DSR are preferred because they discover routes only when needed, thus saving bandwidth and reducing network load. However, high mobility increases the frequency of link failures, leading to packet loss and delays, which is why proactive protocols like OLSR are also evaluated to mitigate these problems [2]. These networks are used in military communications, rescue, disaster recovery, and emergencies where quick setup and self-organization are crucial [3]. MANETs provide reliable communication in environments where conventional network infrastructure is unavailable, such as war zones, remote regions, or space applications [4]. High node mobility and varying node speeds further complicate routing due to frequent topology changes and link failures [5].

In mobile ad hoc networks, how dynamic topologies change and how data packets are routed largely depends on the MANET routing protocol being used. High routing efficiency and throughput are critical in achieving optimal packet delivery ratios (PDR), low end-to-end delays, and reduced control overhead in the network [6]. Within MANETs, routing protocols are generally categorized into proactive and reactive. Proactive routing protocols, for instance, generate and routinely refresh their tables to possess up-to-date routes for every destination, resulting in heightened overhead [7]. Reactive (when needed) on-demand routing protocols, however, generate routes only upon need, meaning they sidestep most routing overhead, thus being better suited for fluctuating networks [8]. In addition to frequent topology changes, the presence of mobile nodes introduces operational challenges at each node, further increasing routing instability [9].

Among the various reactive routing protocols, the Ad-hoc On-Demand Distance Vector (AODV) and Dynamic Source Routing (DSR) are among the most extensively researched and applied protocols within Mobile Ad-hoc Network (MANET) environments. Scalability is a major technical challenge in MANETs, directly related to the degradation in performance as the number and density of nodes in the network increase. As the network expands, the pressure on limited resources, particularly bandwidth and energy, intensifies, leading to a decrease in the efficiency of routing protocols. In high node density scenarios, the flooding process used for discovering new routes, especially in reactive protocols like AODV, can be highly detrimental. When a node broadcasts an RREQ (Route Request) packet, in a dense network, many neighboring nodes retransmit it, leading to a "control packet storm" or broadcast storm [10]. DSR operates on the principle of source routing, wherein the entire route is encapsulated within the packet header, whereas AODV utilizes a hop-by-hop routing mechanism that incorporates destination sequence numbers to maintain routes that are both loop-free and current [11]. Node density, defined as the number of nodes within a given geographical area, significantly influences the performance of routing protocols. A high density of nodes can lead to increased routing overhead and a higher incidence of packet collisions due to the excessive flooding of control packets, while a low density of nodes may result in frequent disruptions in routes and diminished connectivity [12].

A significant challenge in Mobile Ad Hoc Networks (MANETs) is ensuring reliable communication amidst frequent changes in topology due to node mobility. The occurrence of continuous route failures leads to heightened routing overhead and delays, which have a direct impact on the overall performance of the network. Although numerous studies have evaluated routing protocols under specific conditions, comparatively fewer investigations have examined node density as an independent variable in large-scale MANET scenarios. Prior research has

predominantly focused on variations in mobility and speed while maintaining a constant node density, thereby creating a gap in the understanding of how changes in network size influence routing efficiency and scalability [13, 14]. Therefore, the objective of this paper is to conduct a thorough performance evaluation of the Ad hoc On-Demand Distance Vector (AODV) and Dynamic Source Routing (DSR) protocols with increasing number of nodes under controlled connectivity conditions using selected analysis metrics. By analysing packet delivery ratio, end-to-end delay, routing overhead, and throughput under uniform simulation conditions, this study provides clearer insights into the behaviour and scalability of AODV and DSR in large-scale and scalability-sensitive MANET environments.

In addition to the technical scalability challenges, it is equally important to understand the practical implications of routing protocol behaviour in real deployment environments. As network size increases, not only does the number of routing paths expand, but the probability of link instability also rises due to increased interference and shared wireless medium contention. Therefore, evaluating routing protocols solely on the basis of mobility or traffic parameters without considering gradual network expansion may provide incomplete conclusions. A structured scalability-oriented analysis helps in identifying threshold points beyond which protocol efficiency begins to deteriorate. Such insights are particularly useful in applications like emergency response systems and temporary communication setups where network size can grow dynamically after initial deployment. By emphasizing incremental node growth under consistent connectivity assumptions, this study attempts to bridge the gap between theoretical protocol evaluation and practical scalability planning.

2. LITERATURE REVIEW

Several studies have thoroughly analysed the AODV and DSR routing protocols by examining key performance indicators including packet delivery ratio (PDR), end-to-end delay, throughput, and routing overhead. These assessments were conducted under various network conditions, including fluctuations in node mobility, network size, and node density. A thorough and critical analysis of existing research on MANET routing protocols reveals significant research gaps, particularly concerning inconsistent simulation areas, diverse traffic patterns, and the lack of a density-scalable framework, which provide a strong foundation for future research. Firstly, the "inconsistent simulation area" is a fundamental yet often overlooked problem that severely impacts the reliability and comparability of research results; different researchers select varying dimensions for their experiments, with some studies focusing on small areas like $600 \times 600 \text{ m}^2$, while others utilize $1000 \times 1000 \text{ m}^2$ or larger areas. Since the size of the simulation area directly and significantly affects the protocol's performance metrics, especially end-to-end delay and throughput, a performance deemed "optimal" for AODV in a small area might completely fail in a larger one. This inconsistency highlights the absence of a standardized benchmarking framework, as researchers often fail to specify whether their proposed solution scales linearly with spatial scalability, making it difficult to determine if the improvements stem from the protocol's logic or merely from limitations of the simulation environment.

The second major gap lies in the realistic modelling of "diverse traffic patterns"; a large portion of the current literature only utilizes Constant Bit Rate (CBR) traffic, which generates a steady flow of data packets, but this fails to capture the complexity of modern network scenarios where video streaming, voice calls, and bursty data coexist. [15, 16]. Several investigations have found that AODV excels in larger, highly

dynamic networks, while DSR is more effective in smaller networks with lower node density and mobility. At higher mobility levels, DSR's performance often degrades because routes break frequently, and maintaining source routes incurs significant overhead [17].

A review of current literature reveals conflicting conclusions on this matter: while some findings point to DSR offering superior delay performance, other studies argue that Ad-hoc On-demand Distance Vector (AODV) is the better choice for scalability and throughput [16]. These discrepancies are mostly due to differences in simulation environments, simulators (e.g., NS-2, Quante, and OPNET), and variations in simulation parameters, including node density, mobility model, network size, and traffic patterns. MANETs (Mobile Ad-hoc Networks) have significant real-world relevance, particularly in disaster recovery, military convoys, and emergency IoT clusters, as these networks can establish rapid communication without any pre-existing infrastructure. In disaster recovery scenarios, as highlighted in the context of the earthquakes in Turkey and Morocco, traditional telecommunication networks often fail. In such cases, MANETs allow first responders to share critical data, such as video and voice messages, to coordinate rescue efforts. Protocols like CEAODV (Congestion and Energy Aware AODV) are used in these situations, which avoid congested nodes and select energy-efficient routes to conserve limited battery life. [13, 14, 18].

Node density, defined as the number of nodes within a given area, has been identified as a key factor influencing routing overhead, packet collisions, throughput, and overall network stability in Mobile Ad Hoc Networks. The study emphasizes that when "joint traffic" (mixed load) and irregular packet rates are applied to the network, the protocol's behaviour, particularly in terms of energy consumption and packet delivery, differs significantly from the behaviour observed under CBR (Constant Bit Rate), meaning that existing protocols that show high performance under CBR may collapse under real-world mixed traffic loads. Therefore, a significant research gap is that existing studies are often "traffic-agnostic" and lack an adaptation mechanism that can adjust routing decisions by identifying the type of traffic (e.g., video versus text) in real time.

Finally, the lack of a density-scalable framework is the most serious technical obstacle preventing the practical deployment of MANETs; while many protocols perform well at low or medium densities, they suffer from "control packet storms" at high node densities. [19]. When node density is high, it often results in an excessive number of control packets, such as route requests, being flooded, which increases routing overhead and causes congestion within the network [20]. Low node density increases the likelihood of route disconnections, resulting in higher delays and reduced packet delivery rates [21, 22]. Several researchers have reported that low-density environments lead to frequent link failures and unstable routing paths, severely degrading protocol performance in such environments [23]. Although node density is crucial, it has typically been considered a secondary parameter in many studies, which primarily focus on other variable factors such as node mobility and node speed, while keeping density constant [24].

Reactive routing protocols like AODV and DSR create routes only, when necessary, which minimizes unnecessary control traffic compared to proactive methods. Nonetheless, in highly dynamic or densely populated environments, frequent route discoveries can still lead to considerable routing overhead, impacting the scalability and efficiency of the protocol [25]. Although various optimized or enhanced routing protocols have been suggested to boost performance under certain conditions. In

the case of emergency IoT clusters, where thousands of sensors and devices are connected (such as in smart cities or wildfire monitoring), scalability is a major challenge. Traditional AODV protocols struggle in large networks. To address this problem, new methodologies like HMC-AODV (Homogeneous Cluster AODV) have been proposed, which organize nodes into clusters and enhance routing speed and energy efficiency using FPGA hardware. Such critical networks are susceptible to jamming attacks; therefore, protocols like TORA, which provide multiple alternative routes, can help maintain connectivity during attacks.

Thus, the success of MANETs in real-world applications depends on their ability to handle protocol dynamics, conserve energy, and withstand security threats. [26, 27, 28], many of these studies have been conducted on fixed or small network sizes, restricting their relevance to large-scale or dense MANET scenarios. Additionally, much of the existing research emphasizes optimizing individual performance metrics rather than offering a comprehensive evaluation across multiple network densities and consistent simulation conditions. In AODV, the number of control packets increases exponentially with the number of nodes, overwhelming the network. This excessive traffic increases congestion on the wireless channel, leading to collisions and interference between data packets. Consequently, packets are lost and require retransmission, further increasing network latency. Furthermore, in proactive protocols like DSDV, the constant exchange of information to maintain routing tables in large networks results in significant bandwidth wastage. Since bandwidth is already limited in MANETs, this increase in routing overhead significantly reduces the capacity available for actual data transmission. Thus, the root of the scalability problem is that as node density increases, the routing mechanism generates so much overhead that the network throughput drops, and maintaining an acceptable packet delivery ratio (PDR) becomes impossible [29]. Several studies have also pointed out that limitations in node-level resources and protocol inefficiencies can negatively impact network reliability and long-term performance in mobile ad hoc networks [30].

In general, earlier research has predominantly concentrated on small-scale networks, utilized simplified mobility models, and focused on a limited range of performance metrics. There is a scarcity of comparative analyses that consistently evaluate AODV and DSR across different node densities using a standardized experimental framework. The inconsistency in simulation assumptions and the lack of thorough evaluation have resulted in disparate findings within the literature. These deficiencies underscore the necessity for focused and systematic assessment of reactive routing protocols under varying network size and scalability scenarios, which this study intends to achieve.

3. NOTATIONS

Symbol	Description
N	Total number of nodes in the MANET
A	Simulation area ($m \times m$)
Tsim	Total simulation time (seconds)
Smin, Smax	Minimum and maximum node speed (m/s)
v	Node mobility speed (m/s)
R	Transmission range of each node (meters)
PDR	Packet Delivery Ratio
E2E	End-to-End Delay (milliseconds)

ROH	Routing Overhead (total control packets generated)
Pkt_sent	Total data packets sent by source nodes
Pkt_recv	Total data packets received at destination
Pkt_drop	Total packets dropped in the network
CP	Total number of control packets (RREQ, RREP, RERR)
λ	Traffic rate (packets per second)
M	Mobility model (e.g., Random Waypoint)
ρ (rho)	Node density = N / A
D	Number of data flows (CBR connections)
Protocol	Routing protocol under test (AODV or DSR)

4. OBJECTIVE

The objective of this study is to evaluate and compare the efficacy of two widely used reactive routing protocols, AODV and DSR, across increasing network size scenarios in Mobile Ad Hoc Networks (MANETs). The study focuses on understanding how variations in node numbers affect routing behaviour, network connectivity, and overall performance. Special attention is given to evaluating the routing overhead produced by each protocol, as excessive control traffic can result in network congestion and packet loss. Through the application of conventional performance metrics, including packet delivery ratio, end-to-end delay, routing overhead, and throughput, this study aims to identify which protocol optimally utilizes network resources while ensuring consistent performance across different network size scenarios. The focus of the study is on analysing protocol scalability trends rather than evaluating absolute node density effects.

5. PROPOSED METHODOLOGY AND SIMULATION SETUP

This study employs a simulation-based methodology utilizing Network Simulator NS-2.35 to evaluate the performance of reactive routing protocols AODV and DSR within Mobile Ad Hoc Networks (MANETs) under increasing network size conditions. The research modifies the number of mobile nodes to 5, 10, 20, 50, and 100, which correspond to small-scale to large-scale network scenarios. In order to attain a realistic node density and an average node degree, the deployment area has been expanded from $600\text{ m} \times 600\text{ m}$ for 5 nodes to $1200\text{ m} \times 1200\text{ m}$ for 100 nodes. The simulation area is proportionally scaled with respect to the number of nodes to maintain a comparable average node degree and to avoid network partitioning; therefore, the evaluation focuses on protocol scalability with increasing node count rather than absolute node density variation. The simulation area was proportionally scaled with the number of nodes to maintain comparable network connectivity and to ensure that the analysis focuses on protocol behaviour with increasing network size rather than strict node density variation.

Node mobility adheres to the Random Waypoint Mobility Model. Each scenario is simulated for a duration of 99 seconds under Constant Bit Rate (CBR) traffic utilizing UDP, with a packet size of 512 bytes. Both AODV and DSR are exposed to identical mobility and traffic conditions to ensure a just comparison. NSG2 is utilized to generate mobility-aware TCL scripts, which are then executed in NS-2. The trace files generated during the simulation are examined using AWK scripts to extract quantitative performance metrics. The key simulation parameters used in this study are summarized in Table 1

Table 1. Simulation Parameters

Parameter	Value
Simulator	NS-2.35
Routing Protocols	AODV, DSR
Node Count	5, 10, 20, 50, 100
Simulation Area	600×600 to 1200×1200 m ²
Mobility Model	Random Waypoint
Traffic Type	CBR over UDP
Packet Size	512 bytes
Simulation Time	99 seconds
Trace Analysis	AWK scripts

It is important to highlight that maintaining comparable network connectivity while increasing the number of nodes was a deliberate experimental design choice. Instead of keeping the simulation area fixed, proportional scaling ensured that node degree and communication probability remained within a realistic operational range. This approach prevents artificial congestion or forced partitioning that may occur in fixed-area experiments when node count rises significantly. Furthermore, identical seed values and traffic generation patterns were maintained across simulation runs to minimize random bias. Each scenario was executed multiple times, and average values were considered to ensure result consistency. Such methodological precautions strengthen the reliability and reproducibility of the presented findings.

6. PERFORMANCE METRICS

To evaluate the performance of AODV and DSR under increasing network size conditions, the following metrics are used:

6.1 Packet Delivery Ratio (PDR)

PDR represents the ratio of the total number of packets successfully received at the destination to the total number of packets sent by the source. A higher PDR indicates more reliable communication. It is one of the primary indicators of routing efficiency.

$$PDR = \frac{Pkt_recv}{Pkt_sent} \times 100 \quad (1)$$

Where:

- Pkt_recv = total packets received
- Pkt_sent = total packets sent

6.2 Packet Drop Ratio

The Packet Drop Ratio (PDR_DROP) quantifies the proportion of transmitted packets that fail to reach their intended destination under given network condition. It is used as a measure of the reliability of routing protocols in different network conditions. A high drop ratio indicates subpar performance, suggesting that a larger number of packets are lost due to issues like congestion, collisions, link failures, or routing mistakes. This metric holds particular importance in Mobile Ad Hoc Networks (MANETs), where the constant movement of nodes and restricted bandwidth

frequently lead to route instability. In this research, PDR_DROP is utilized to assess the performance of AODV and DSR across different network size scenarios and to investigate whether an increase in control traffic results in a higher incidence of packet losses.

$$Packet\ Drop\ Ratio = \frac{(Packets\ Received)}{Packets\ Sent} \times 100 \quad (2)$$

6.3 End-to-End (E2E) Delay

This metric evaluates the mean duration required for a packet to travel from the source node to the destination node. It takes into account delays caused by route discovery, queuing, retransmissions, and propagation. Reduced delay values indicate faster and more efficient routing.

$$E2E = \frac{\sum_{i=1}^n (t_{recv,i} - t_{send,i})}{n} \quad (3)$$

Where:

- $t_{recv,i}$ = receiving time
- $t_{send,i}$ = sending time
- n = total received packets

6.4 Routing Overhead

Routing Overhead (ROH) denotes the aggregate number of control packets generated throughout the route discovery and maintenance phases. This includes packets such as RREQ, RREP, and RERR. An elevated routing overhead indicates that the protocol consumes additional bandwidth and energy to maintain routes, potentially detrimentally affecting network performance, especially in large-scale network scenarios with increased control traffic.

$$ROH = \frac{CP}{Pkt_recv} \quad (4)$$

In this study, routing overhead values represent normalized control packet counts obtained from NS-2 trace analysis using AWK scripts.

Where:

$$CP = RREQ + RREP + RERR \text{ (total control packets)}$$

6.5 Throughput

Throughput is a performance metric that represents how much data is successfully delivered from source to destination per unit time, reflecting the actual efficiency and capacity of a network. In MANETs, it is usually expressed as the total successfully received data in units such as bits per second (bps), kilobits per second (kbps), or bytes per second (Bps) over the simulation or observation interval.

$$Throughput = \frac{Total\ Data\ Received\ (in\ bits)}{Simulation\ Time\ (in\ seconds)} \quad (5)$$

These metrics help in understanding protocol behaviour under increasing network size and scalability conditions while maintaining comparable network connectivity.

7. RESULTS AND DISCUSSION

This section presents a comprehensive quantitative evaluation of the Ad-hoc On-Demand Distance Vector (AODV) and Dynamic Source Routing (DSR) protocols. The comparative analysis focuses on four critical performance metrics: End-to-End Delay, Routing Overhead, Packet Delivery Ratio (PDR), and Throughput. These metrics were analysed under increasing network size scenarios ranging from sparse networks (5 nodes)

to large-scale network scenarios (100 nodes) to determine the scalability and efficiency of each protocol.

Table 2. End-to-End Delay Comparison (seconds)

Node Count	AODV	DSR
5	0.009	0.0134
10	1.1042	0.1430
20	1.1813	1.2296
50	1.0746	1.3793
100	1.7091	2.2625

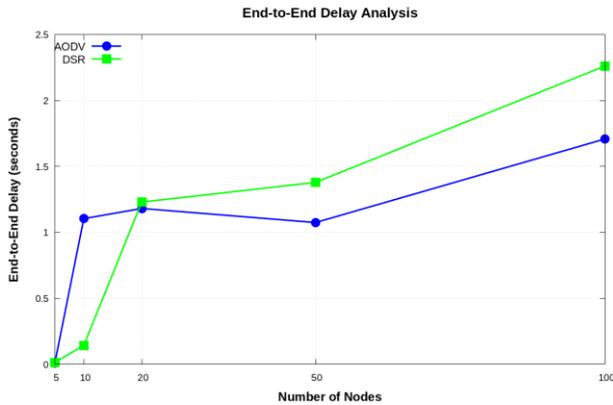


Fig 1. End to end delay of AODV and DSR

As observed in the experimental results, the end-to-end delay for both routing protocols increases as the network size (number of nodes) grows. This is primarily due to increased network congestion and longer routing paths. However, DSR exhibits a significantly higher delay compared to AODV in larger networks. This happens because DSR relies on source routing, where the entire routing path is stored in the packet header. As the network grows, the header size increases, leading to processing delays. Furthermore, DSR uses aggressive route caching; in a highly dynamic or larger network, these cached routes often become stale, causing packet drops and initiating new, time-consuming route discovery processes. In contrast, AODV maintains lower delay by using hop-by-hop routing and destination sequence numbers, ensuring fresher routes.

Table 3: Routing Overhead Comparison

Node Count	AODV	DSR
5	0.13	0.11
10	0.4	0.43
20	0.55	0.99
50	11.78	4.45
100	13.82	1.35

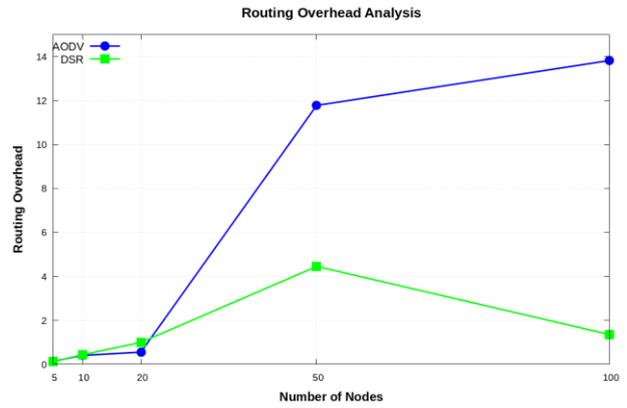


Fig 2. Routing Overhead of AODV and DSR

The routing overhead results indicate a clear distinction between the two protocols. AODV shows a consistently higher routing overhead compared to DSR as the number of nodes increases. This behaviour can be attributed to AODV's route maintenance mechanism, which relies on periodic 'HELLO' messages to detect link breakages. When the network size scales up, the broadcast of Route Request (RREQ) packets and HELLO messages floods the network, leading to a surge in control packets. On the other hand, DSR generates less routing overhead because it does not use periodic HELLO messages and relies heavily on overhearing and caching multiple routes, thereby reducing the need for frequent route discovery broadcasts.

Table 4. Packet Delivery Ratio (PDR %)

Node Count	AODV	DSR
5	98.93	100
10	90.3	98.91
20	87.06	86.85
50	85.54	84.24
100	82.52	83.49

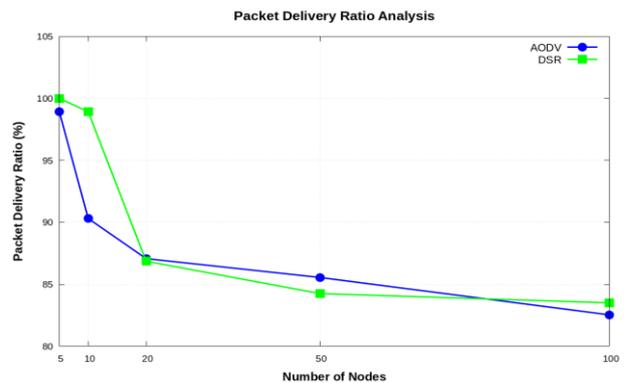


Fig 3. Packet delivery ratio of AODV and DSR

The Packet Delivery Ratio generally shows a declining trend for both protocols as the network density increases, which is a common characteristic of MANETs due to increased packet collisions and MAC layer contentions. AODV outperforms DSR in terms of PDR, especially as the network scales. AODV's table-driven approach for active routes and its mechanism to quickly drop stale routes via Route Error (RERR) messages ensures that data packets are transmitted over valid paths. DSR's reliance on

cached routes becomes a bottleneck here; transmitting data over broken cached links leads to higher packet loss before the source is notified to find a new route.

Table 5. Throughput Comparison (Kbps)

Node Count	AODV	DSR
5	311.55	300.05
10	234.6	247.31
20	178.44	171.21
50	190.99	195.45
100	669.37	651.10

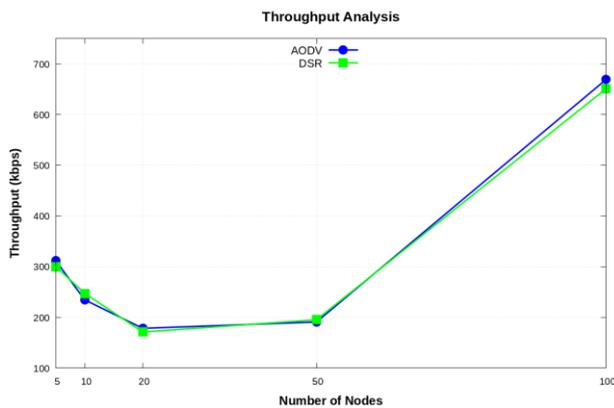


Fig 4. Throughput of AODV and DSR

Throughput is directly influenced by the PDR and routing overhead. The tabular and graphical data reveal that AODV maintains a more stable and higher throughput than DSR in larger network scenarios. Because AODV establishes fresh routes on demand and manages link failures efficiently without relying on potentially outdated caches, more data packets successfully reach their destinations per unit of time. DSR's throughput degrades in denser networks because the higher end-to-end delay and stale-cache-induced packet drops consume valuable bandwidth, thereby reducing the overall successful data transmission rate.

A broader interpretation of the obtained results suggests that scalability behaviour is not linear and cannot be predicted solely based on low-density observations. While both protocols demonstrate acceptable performance in small network configurations, performance divergence becomes evident as network size increases. This divergence reflects differences in internal routing mechanisms, packet header structures, and control message handling strategies. It is also noteworthy that performance trade-offs are unavoidable; a protocol optimized for lower routing overhead may incur additional delay under heavy load, whereas a protocol designed for faster route maintenance may consume more bandwidth. Therefore, protocol selection should be guided not only by average metric values but also by anticipated scalability thresholds and application-specific reliability requirements. These findings reinforce the necessity of multi-metric evaluation when assessing MANET routing protocols under evolving network dimensions.

8. CONCLUSION

This study carried out a comparative assessment of the AODV and DSR routing protocols' performance in Mobile Ad Hoc Networks (MANETs) across various network size levels. The

simulation outcomes reveal that network size and scalability effects play a crucial role in determining routing efficiency and overall network performance under controlled connectivity conditions. It should be noted that the conclusions drawn in this study are limited to the considered simulation settings and controlled connectivity scenarios.

The analysis indicates that DSR performs effectively in low-density network environments, primarily due to its route caching mechanism, which reduces routing overhead and improves packet delivery efficiency. However, as the number of nodes rises, the source routing approach employed by DSR leads to longer end-to-end delays and presents scalability issues. In contrast, AODV demonstrates more consistent performance in scenarios characterized by medium to large network sizes, as it sustains lower delays and attains better throughput, thereby rendering it more appropriate for implementation in dense MANETs.

In summary, the results validate that there is no universally optimal routing protocol applicable to all network scenarios. Consequently, the choice of a suitable routing protocol should be determined by anticipated network size, scalability requirements, and specific application needs. This research offers valuable perspectives on protocol performance amid variations in density and can aid both researchers and network architects in selecting appropriate routing approaches for Mobile Ad Hoc Network (MANET) settings. The conclusions drawn in this study emphasize relative scalability trends rather than absolute performance guarantees under all possible MANET configurations.

9. LIMITATIONS

Although this research provides significant insights, it is not without its limitations. The simulations were performed over a limited duration and within a fixed network area, which may not accurately represent the long-term dynamics of the network. The analysis focused solely on one traffic pattern and mobility model, while actual MANET situations could encompass a range of traffic loads and movement behaviours. Although longer simulation durations could further improve routing stability analysis, the selected simulation time was sufficient to capture consistent relative performance trends across all evaluated scenarios. Although the simulation was conducted within a predefined area, the network dimensions were scaled proportionally with node count to preserve comparable connectivity across all scenarios.

Additionally, the evaluation of performance was based on simulation results, which depend on the accuracy of the simulation parameters and underlying assumptions. Factors such as hardware constraints, environmental disturbances, and unpredictable mobility were not included in the analysis. As a result, the conclusions should be interpreted as indicative trends rather than definitive guarantees of performance.

10. FUTURE SCOPE

Future work can extend this study by incorporating diverse traffic patterns, advanced mobility models, and longer simulation durations to better capture realistic MANET scenarios. Additionally, security-aware simulations involving malicious nodes and routing attacks can be conducted to evaluate protocol robustness under adversarial conditions. Further validation using NS-3 simulations or real-world testbed implementations would enhance the practical relevance and reliability of the findings.

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