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Assessing MANET Routing Protocols: Comparative Analysis of Proactive and Reactive Approaches with NS3

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ABSTRACT

MANETs are dynamic, decentralized networks that employ mobile nodes as hosts and routers. High mobility and frequent topology modifications make routing tricky in these networks. This research compares the efficacy of four MANET protocols: DSR, AODV, OLSR, and DSDV. We evaluate various protocols utilizing the NS3 simulator for PDR, throughput, control overhead, and delay. We analyze each protocols strong points and weaknesses under varied node densities, pause durations, and network sizes. DSR has the greatest PDR and lowest control overhead, making it ideal for dynamic networks. OLSR maintains high throughput and short delay despite increasing control overhead. DSDV has the maximum throughput but significant control overhead and PDR in bigger networks. AODV performs well in smaller networks but degrades significantly as network size rises. This research illuminates MANET routing protocol trade-offs, helping to build more resilient and efficient communication techniques for diverse application situations. Our results imply that DSR is best for dynamic contexts and OLSR for route availability and low latency.

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1. INTRODUCTION

MANET nodes link to other nodes despite infrastructure on the go. All nodes may interchange information and forward packets via these links [1]. Each node works as a router to transmit data packets between the source and the destination [2]. MANET is typically utilized in conflict and catastrophe zones where infrastructure is pricey or difficult to build [3]. MANET nodes are free to relocate, providing frequent and unexpected modifications to the topology that hinder routing. MANET reliability and performance depend on efficient routing. Mobile Ad hoc Networks may operate alone or in a larger network. The transceivers connecting nodes from a highly dynamic and independent topology that varies frequently. Training each device to route traffic appropriately is MANET's largest challenge. Starting with environmental sensors may improve road safety. MANET offers several great features, including topology flexibility, reliability, quick configuration, intrinsic quality assistance, superior geographic coverage, internal failure adaptability, self-healing, and free-gathering framework features [4]. MANET routing involves finding, establishing, and maintaining routes between mobile nodes. Packet routing may be single-hop or multi-hop [5]. MANETs are multi-hop wireless ad hoc networks due to their unique characteristic [6]. Data packets must be sent via multi-hop wireless communication within the network. New MANET technology highlights the importance of multi-hop communication [7]. Modern society requires a system that allows individuals to communicate with minimal resources, time, expense, and multi-user support. To acquire this framework, WSN are built. All sensing devices can transmit, conclude, decide, and self-regulate. WSN sensors process large amounts of raw data into useable information for event assessment. These sensors form a mesh network that exchanges massive amounts of data via WSN [8]. Fixed infrastructure and centralized administration characterize traditional wireless networks. Installing and maintaining these networks takes time and money. Another form of network requires no infrastructure is called MANET [9].

Due to limited resources, MANETs have struggled to establish a viable routing algorithm. Intelligent routing strategies optimize resource consumption and adapt to changing network circumstances such network size, traffic density, and network partitioning. To offer QoS for MANET applications, an efficient routing protocol is needed [10]. Over the last fourteen years, ad-hoc network technology has made numerous noteworthy academic contributions. This area has been studied by many researchers to improve their knowledge. MANET's frequent topology modification causes several issues and obstacles. New MANET research includes routing and maintenance, energy efficiency, multicasting, clustering, and mobility management [11]. MANETs are promising due to their simplicity of use, robustness, speed of deployment, and low cost. However, MANETs have many limitations, including their mobile and dynamic architecture, constant node mobility, safety risk owing to cooperation, and poor computation capabilities due to tiny devices [12]. MANETs are utilized for emergency and disaster management, battlefield mobile services, and Communications. It also aids enterprises who need wireless navigation [13].

Proactive, reactive, and hybrid routing protocols are the three basic types of routing protocols utilized by MANETs. Proactive protocols like OLSR and DSDV update routing information periodically, assuring rapid route availability but increasing control overhead. Reactive protocols like AODV and DSR identify routes on-demand, reducing control overhead but perhaps delaying route discovery. Hybrid methods balance control overhead and route discovery delay with proactive and reactive techniques [14]. The major contribution of this paper as follows:

- Firstly, we consider a dense network to assess the effectiveness of four key MANET protocols- DSR, AODV, OLSR and DSDV using NS3 simulator. We consider a maximum 350 nodes, which is more than any other paper has considered. This analysis focuses on critical performance metrices such as PDR, throughput, control overhead and delay.
- Secondly, we have considered three phases here: varying the number of nodes, varying pause times and varying physical network sizes. This comprehensive evaluation helps in understanding the strengths and weaknesses of each protocol in different scenarios.

The rest of the paper is summarized as follows. Section 2 represents the literature review, section 3 represents the MANET routing protocols, section 4 represents performance metrices, section 5 represents results and discussion and finally section 6 represents the conclusion of this work.

2. LITERATURE REVIEW

V. Balaji et al. offer a comprehensive analysis of how traditional MANET routing protocols perform in D2D environments. Their study investigates the adaptability of various protocols, such as DSR, AODV, OLSR, and DSDV in the dynamic and often unpredictable conditions characteristic of D2D communication networks. The evaluation is conducted using various performance metrics that capture the effectiveness and reliability of each protocol in managing the challenges posed by D2D scenarios. Their findings suggest that hybrid protocols, which combine the proactive maintenance of routing tables with reactive route discovery mechanisms, could potentially address the limitations of existing routing methods. This aligns with recent trends in MANET research that advocate for adaptive and intelligent routing protocols capable of dynamically adjusting to the varying conditions of D2D networks [15]. Ahmed et al. contributes to the growing body of research that seeks to understand and optimize MANET routing protocols for drone communication networks. By evaluating the performance of DSR, AODV, and OLSR in drone-specific scenarios, the authors findings highlight a critical trade-off in drone communication networks: while reactive protocols like AODV and DSR can efficiently handle dynamic topologies, they suffer from increased latency. Proactive protocols like OLSR offer more stable communication but incur a higher control message overhead, which can limit their scalability in larger drone networks. The authors suggest that future work should explore hybrid routing protocols that combine the strengths of both reactive and proactive methods to address these limitations. Their findings emphasize the need for developing new or hybrid routing protocols that can efficiently handle high mobility and ensure reliable communication while minimizing control overhead. This study sets the stage for future research in designing advanced routing mechanisms tailored to the unique requirements of drone communication networks [16]. Furthermore, Mukherjee et. al. performs a comprehensive analysis of several key MANET routing protocols, including AODV, DSR, OLSR, and DSDV. Their study evaluates these protocols using various performance metrics such as PDR, throughput, end-to-end delay, and control overhead under different network conditions. The authors has employed simulation-based experimentation to determine how each protocol adapts to the dynamic nature of MANETs, aiming to identify the optimal protocol for different network scenarios. One of the significant contributions of Mukherjee and Mohapatra's study is the thorough investigation of protocol performance under high mobility conditions**.** The authors observe that reactive protocols like AODV and DSR, which establish routes on-demand, tend to outperform proactive protocols like OLSR and DSDV in environments with frequent topology changes. The study further emphasizes the performance of proactive protocols like OLSR and DSDV in static or low-mobility scenarios [17].

A study by Khan et. al. offers a comprehensive evaluation of three key MANET routing protocols: AODV, DSR, and MP-OLSR. AODV and DSR are well-known reactive protocols that establish routes only when needed, while MP-OLSR is a proactive protocol designed to maintain multiple routing paths proactively. The main objective of this research is to understand how these protocols perform under different MANET scenarios and identify their strengths and limitations, thereby contributing to the improvement of MANET routing mechanisms. In this study, Khan employs various performance metrics such as PDR, end-to-end delay, throughput, and control overhead to assess each protocol's effectiveness in managing the complexities of MANETs. One of the significant findings from Khan's study is the efficiency of reactive protocols like AODV and DSR in dynamic environments. In contrast, the proactive MP-OLSR protocol shows its strengths in more stable and less dynamic network environments. A notable contribution of this study is its emphasis on exploring hybrid routing solutions. Given the limitations identified in both reactive (AODV, DSR) and proactive (MP-OLSR) protocols [18]. Al-Nasir et. al. focuses on three widely-used MANET routing protocols: AODV, DSDV and DSR**.** The objective of this research is to compare the performance of these protocols in VANET environments using NS-2. Their work contributes to the understanding of how traditional MANET routing protocols perform under the high mobility and rapidly changing topology characteristic of vehicular networks. Al-Nasir and Mubarek's comparative analysis reveals that no single protocol performs optimally across all VANET scenarios. While AODV and DSR are more adaptable to dynamic topologies, they suffer from increased end-to-end delays during the route discovery process. On the other hand, DSDV offers low latency but incurs high control overhead, which affects its scalability and efficiency in high-mobility environments. This study highlights the need for a balanced routing strategy that can adapt to the rapid changes in vehicle movement while minimizing latency and control message overhead. The findings suggest that hybrid routing protocols could potentially address the limitations of individual protocols by combining the proactive and reactive mechanisms [19]. Khanchandani et. al. presents a comprehensive analysis of both proactive and reactive routing protocols using the NS-3 simulator. The study focuses on two popular proactive protocols—DSDV (Destination-Sequenced Distance Vector) and OLSR (Optimized Link State Routing)**—**alongside two widely used reactive protocols—AODV (Ad-hoc On-Demand Distance Vector) and DSR (Dynamic Source Routing). The objective of this comparative study is to evaluate the performance of these protocols based on key metrics such as Packet Delivery Ratio (PDR), throughput, end-to-end delay, and control overhead. By simulating these protocols in different network scenarios, the study aims to highlight their strengths and weaknesses, thereby providing insights into which protocols are best suited for specific MANET conditions [20].

In an article by Sabah M. Alturfi et al., network performance under significant congestion load is examined and assessed when three distinct types of protocols are configured on heterogeneous nodes. Based on the simulation outcomes, the Dynamic Source Routing (DSR) protocol performs best regarding network load, whereas the OLSR protocol achieves the maximum throughputs [3]. Chetana Hemant Nemade et al. explain major technological advancements and discuss the features and drawbacks of cutting-edge advanced routing techniques. Traditional routing techniques recommended for wired networks, like distance-based vector and link status protocols, are not suitable for this application because of their large overheads and assumption of static geography. The contributors also cover MANET-supported routing techniques and analyze their effectiveness based on a variety of issues, such as average PDR, throughput, residual energy and delay [4]. In order to compare three sets of MANET routing protocols, Baidaa Hamza Khudayer et al. assess each sets aspects and approaches regarding scalability, delay, routing overhead, and other factors. It depicts how reactive protocols initiate route discovery only when data has to be transferred, although proactive techniques make sure route availability but endure with scalability and overhead [5]. Huda A. Ahmed et al. examine and evaluate the effectiveness of a variety of widely used conventional protocols in MANETs like DSR, DSDV, AODV and OLSR. The evaluation spans several wireless node quantities, ranging from 10 to 100, and also examines multiple performance metrics. The findings indicate that the OLSR routing protocol performs better than the others in nearly all metrics for video transmission. However, when applied in multimedia applications, traditional routing protocols have insufficient resources that could result in link failures and increase power and bandwidth requirements [6]. Abdul Rahman et al. analyzes various WSN routing protocols to highlight their suitability for different area sizes and network density in practical uses. The effectiveness of DSR, OLSR and AODV is compared over four distinct area sizes with varying node densities. Furthermore, the role of protocol runtime on the size of each area is taken into account. To ascertain DSR, OLSR, and AODV, the scenarios were simulated using the OPNET 14.0 [8]. Dr K S Balamurugan et al. propose a number of ways to enhance routing quality. Advancenments include considering congestion and available bandwidth, as well as assessing received signal power. Route efficacy is increased by choosing hosts with more resources, and routes have a longer lifespan when nodes have more residual energy. These advancements were applied in selected multipath protocols and their outcomes were analyzed. The traffic Free and Bandwidth Aware AOMDV protocol uses a mix of Congestion Free Transmission (CFT) and residual bandwidth evaluation to determine the optimal path [9].

A paper by Balqees AL-Hasani et al. looks at the selection of the most prominent MANET routing protocols and evaluates how well they execute in sense of entire latency, routing overhead, throughput, and average volatility. The effectiveness of these strategies is determined in a range of operational scenarios, incorporating changing the size of the terrain to depict a range of node densities in many dimensions. Additionally, the volume of data exchanged is varied by shifting the number of bit-rate connections for the same network size [10]. Furthermore, in his work, Abdul Majid Soomro et al. elaborate the routing and upkeep strategies of MANETs, which include flexible topologies and nodes that enable rapid data delivery, are the main matters of this research. The research depends on route discovery, representing several suggested techniques, each designed to exceed the efficiency of the others. This contrary analysis highlights challenges in route discovery and maintenance for MANET interaction, evaluating which techniques perform better under various network conditions [11]. Sakshi Mishra et al. compares table-based routing system (DSDV) with methods for on-demand routing (DSR, and AODV) in terms of aspects and overall performance. Functioning metrics assessed include the number of eased packets, delay, PDR, forwarding overhead, node mobility, and the impact of expanding node numbers. Finally, the Dynamic Source Routing (DSR) protocol outperforms the remaining two in typical scenarios [12]. Moreover, Sandeep Singh et al. discusses the performance metrics such as packet size, speed, packet rate, types of Transmission Control Protocol (TCP), number of packets, and network energy. According to the simulation results, DSR performs more successfully than AODV and DSDV [13].

Ahmed M. Eltahlawy et al. combine a variety of environmental characteristics that are required to build up the necessary environment. To assess network performance under attack, they also gather parameters that evaluate overall performance. A survey of fifty recent articles is carried out to examine the literature contributions. These contributions and the parameters that were used are shown in statistical charts and comparison tables. Results indicate that simulator NS-2 is the most frequently employed simulator in MANET research [21]. Dr. Mamatha C.M et al. investigate routing techniques that are lossy networks and low on power in Smart Grids, specifically comparing RPL and LOAD. The article analyzes the performance of these protocols with different traffic conditions, including CBR, FTP, and TELNET, in MANETs. Furthermore, it evaluates the effectiveness of public safety network routing protocols (RIP, OSPF, IGRP, and EIGRP), emphasizing queuing delay, throughput, and convergence [22]. Kavitha Balamurugan et al. introduce a unique algorithm to enhance MANET performance using FSO (Free-Space Optics). FSO is very compatible because they have a wide bandwidth, and naturally resists interference. Its low power consumption and adaptability make it suitable for advanced innovations, such as SANs and WANs. The contributors suggest work utilizes optical spheres with a cross-layered reconfigurable routing mechanism and a multi-transceiver system. The effectiveness of the CRHROS technique is evaluated for various numbers of optical transceivers using characteristics including packet drop, throughput, residual energy, and latency [23]. Kathirvel A et al. boost the efficiency of reactive protocols in MANETs. They highlight on implementing and analyzing the AODV routing protocol. Four particular studies are selected for examination and possible techniques for performance enhancement. These tactics are designed with the needs and circumstances in which MANETs are utilized [24]. To provide secure routing, Md. Torikur Rahman et al. suggest a protocol that combines a number of security features, such as key management, encryption, authentication, and intrusion detection. The protocol's objective is to reduce attack risks, maintain network resources, and deliver messages to their intended locations securely and swiftly. Simulation results present that the proposed protocol exceeds existing routing protocols in both network performance and security [25]. Ali H. et al. shows the several routing techniques suggested for UAV ad hoc networks. OLSR, D-OLSR, ML-OLSR, and P-OLSR are the four routing protocols whose efficiency is analyzed and compared regarding latency, energy consumption, throughput, and PDR. In the case under analysis, an attempt at search and rescue is conducted. A search area that is rectangular is formed, and many UAVs are used to speed the task [26].

Veepin Kumar et al. provide a brief overview of MANET and its routing protocols. They then carry out a detailed examination of these protocols based on various performance measures. The simulation utilizes throughputs, energy usage, PDR, and end-to-end latency as performance indicators. The performance analysis is conducted using the NS2.35 simulator [27]. Dr. L V Raja offers a protocol that uses information from nodes that have overhead the main communication to keep broken routes functional. The protocol instantly moves to standby nodes, which are backups that are placed in key locations close to the main channel, in the event of a connection failure. Generalization is difficult since ad-hoc networks are employed in many different daily activities [28].

Aiswarya Asokan et al. presents the outcomes of research on three methods: AODV, DSR, and DSDV. The authors utilized the NS2 simulation environment, which is the latest available. They analyzed the methods based on received packets, routed packets, sent packets, overhead, and packet delivery ratio. All nodes in the network must take part in the discovery process, even if they are unable to help create the route, because flooding is necessary for both phases of route discovery, which adds to the network burden. The program was run successfully, and the routing protocols effectiveness was evaluated [29]. In order to create an optimal solution, an article by J. Deepika et al. performs a thorough analysis of the conventional protocol's performance. The authors examined throughput, message rate, communication range, and proposed an modified edition of the AODV protocol. They designed and simulated the new algorithm using a software tool, and plotted the results. These results demonstrate that the enhance version provides optimized solutions for various metrics [30]. To determine the most efficient route, Lakshi Dhiman et al. investigates several routing protocols. These protocols are commonly grouped into three types: Hybrid, Reactive and Proactive. Even with a large number of nodes and increased mobility speeds, AODV works better than the other routing protocols comparing to a review of the literature [31].

G. M. Walunjkaret al. highlights the inadequacy of protocols for routing created for wired networks, such as distance-based vector or link status protocols, for use in ad hoc networks due to their assumption of a mostly fixed topology and high overheads. Due to this limitation, a number of routing procedures tailored for MANETs have been developed. The author examines the efficiency of MANET supported routing protocols over a range of factors [32]. In addition, W. Adi Saputra al. emphasizes how excessive overhead and the assumption of a fixed topology make routing techniques meant for networks that are wired, like distance-based vector or link status protocols, inadequate for use an ad hoc network. Due to this constraint, many routing algorithms tuned for ad-hoc networks have been developed. The authors include routing protocols facilitated by MANET and analyze how well they performed using diverse metrics [33]. In order to examine the PDR and AETED of four distinct routing techniques, a work by Russell Skaggs et al. simulated them in NS-3 with changeable movement rates and area sizes. The value of choosing the adequate protocol for a system is illustrated by the efficiency results, which offer insights into how a structure might operate in a comparable setting [34]. Using various loads and network sizes, Kedir Lemma et al. examined the effectiveness of DSR, AODV and DSDV according to packets transmitted and received as well as QoS metrics as throughputs, entire latency, PDR and PLR [35]. Md. Navid Bin Anwar et al. examined the effectiveness of three key routing protocols- SDV, DSDV and OLSR protocols, both in the existence and lack of a black hole invasion using a variety of metrics [36].

Mohammad Alnabhan et al. demonstrate that routing protocol implementation is a useful tool to analyze MANET performance. Due to the constant mobility of mobile nodes, MANETs often encounter topology changes, which provide serious performance issues. Various MANET routing strategies are available, grouped mainly into geographical placed based and architecture-based protocols. To determine the best routing protocols for attaining the highest performance under various environmental conditions, such as terrain areas, node density, and mobility speeds, this work presents a new framework for performance evaluation [37]. Md Ashek Raihan Mahmud used CBR and FTP payloads to compare how well two protocols performed in various situations. The main simulator for the simulation was NS2, which was used along with network animator and trace graph to create graphs from trace files. The outcomes clearly present that the protocols show different behaviors under varying conditions. Based on their performance, the findings also highlight the salient features of each methodology, indicating areas for possible developments [38]. G. Raj Kumar et al. compares and analyzes the OLSR and AODV routing protocols performance characteristics in both static and dynamic scenarios. Depending upon the investigation, under static conditions, AODV regarding packet delivery ratio and throughput, but under dynamic conditions, OLSR operates more effectively than the AODV regarding control overhead and average energy usage [39]. Pushpender Sarao et al. highlighted the DSR, AODV, and DSDV protocols in wireless MANETs. They use normalized routing load, entire latency, and average throughput as metrics to compare these protocols. The study assumes low node mobility within the network. They investigated each protocols performance over a range of simulation times, evaluating the effectiveness of both reactive (DSR, AODV) and proactive (DSDV) routing protocols [40].

To solve the problem, Lakshman Naik et al. uses a simulation model that combines updated versions of the widely used AODV, DSDV, and OLSR routing protocols in MANETs with a universal network scenario. Using the network simulator NS3 and a variety of performance evaluation measures, the authors examined the operation of a unique 802.11 mobile ad hoc network [41]. Lucas Rivoirard et al. evaluated routing protocols consisting DSR, OLSR, DODV and GRP (Geographic Routing Protocol). They took into consider mobility models based on actual traffic traces as well as application requirements for vehicular safety. The findings show that, even with a respectable number of cars, none of the four proactive routing systems satisfy application requirements for delay metrics, despite the fact that they perform better in this simulation [42]. Three standard routing protocols- AODV, DSDV, and DSR have been evaluated by Sandeep Sharma et al.. Using the NS-2.34

simulator, the comparison depends on three performance indicators, like routing overhead, packet delivery ratio, and remaining energy [43]. In an article by Ranichitra A et al., node behavior deploying NS2 is investigated by changing the number of connections and break intervals using two popular routing protocols: AODV and DSDV. A variety of performance criteria are used to compare and assess the methods [44]. The NS-2 simulator was used by Fan-Shuo KONG et al. to simulate the DSDV, DSR and AODV routing protocols. They assessed and compared the effectiveness for each protocol depending on PDR, average delay and overhead. Also, they carried out simulations by changing the transmitting rate of the sending node and using various halt times, utilizing a CBR source traffic templates and node movement model [45]. By the assistance of HTTP image inspecting traffic, a work by Gharamaleki et al. assesses MANET routing protocols, such as DSR, AODV, TORA and OLSR. The delay and throughput as function of load are the efficiency indicators used for evaluation. According to the outcomes, the AODV performs superior overall regarding delay and throughput [46]. To figure out which is more beneficial, Naseer Sabri et al. analyze and contrast the effectiveness between DSR and AODV as a reactive routing protocol. Based on various metrics, NS 2.35 version network simulators were used to imitate and assess these protocols efficacy [47].

Khandaker Takdir Ahmed et al. evaluate the efficacy of AODV, DSR, and DSDV, with a particular emphasis on FTP and CBR traffic with diverse pause durations. There is no change in the volume of nodes, mobility speed, or simulation periods. The conclusion of this analysis detects the best protocol among the three [48]. Md. Repon Hossen et al. demonstrates that the MANET routing protocols performance under various situations and limitations is a rapidly developing field of study. The study compares three MANET protocols- AODV, DSDV, and DSR with respect to UDP and TCP traffic. To highlight the distinctions between UDP and TCP traffic, the authors take consideration of a network situation with specified nodes and fixed pause times while adjusting the nodes mobility speed [49]. Md. Khanjahan Ali et al. uses UDP payload (CBR traffic) to compare three routing protocols according to how well they work in different situations. For the simulations, NS2 was used as the primary simulator, supplemented by network animator and trace graph for graph preparation via trace files. The findings clearly show that each protocol exhibits distinct behaviors across different environments [50]. Abdelmuti Ahmed et al. investigates the effectiveness of reactive and proactive routing protocols under particular application traffic, reflecting real-world scenarios more closely. Various routing protocols are available for MANETs. The study compares the effectiveness of a proactive protocol (OLSR) and reactive protocols (DSR and AODV). Performance metrics are used in the comparison to assess these protocols [51]. Divya Bandral et al. simulated and examined two popular routing protocols- AODV and DSDV based on the quality of packets and nodes. Throughput, entire delay, and packet loss ratio were the performance metrics that were compared. The outcomes show that the AODV protocol outperforms DSDV regarding QoS parameters [52]. In an article by R. F. Sophia et al., the capabilities of these protocols are compared under various scenarios using three performance metrics- PDR, Delay and Overhead. In contrast to the AODV and DSR protocols, the comparison shows that the DSDV protocol has very high control overhead but poor packet delivery. While AODV performs better in some cases, DSR outperforms AODV overall [53]. Smt. Rekha et al. analyze, simulate, and perform a comparative analysis of various mobility models using MANET routing techniques, namely OLSR and AODV. Different performance measurements will be used as the basis for comparison [54]. Moreover, performance issues are still present even after numerous routing protocols for MANET have been developed and published in the literature. This is because Anil Saini et al. decide to assess DSDV, AODV, and DSR three widely used routing protocols for performance. The analysis considered variations in node density, routing energy usage, and network size were taken into consider in the evaluation. Using the NS2 simulator, a simulation model with scenarios spreading from 50 to 500 nodes and 8 UDP connections was created in order to examine inter-layer interactions and evaluate protocol performance [55].

Ms. Sunita Sharma et al. used simulation to assess and examine the effectiveness of three MANET routing protocols: DSDV, AODV, and OLSR. They developed an appropriate routing protocol to satisfy predetermined network conditions and desired objectives based on through simulation results and analysis [56]. Tarunpreet Bhatia et al. analyzes the performance of the hybrid protocol ZRP, as well as the proactive protocols (OLSR and DSDV) and the reactive protocols (DSR and AODV). This analysis evaluates various performance metrics, providing a quantitative basis to guide the choice of the most appropriate protocol specific to a network and objective [57].

P. Mohapatra et. al. introduced ad hoc networks as decentralized wireless networks that enable direct communication between devices without relying on a pre-existing infrastructure. The author discusses various challenges associated with ad hoc networks, such as dynamic topologies, limited bandwidth, energy constraints and security concerns. These challenges necessitate the development of specialized routing protocols and communication techniques that can adapt to the constantly changing conditions within the network. The author emphasizes the importance of scalability and adaptability in ad hoc networks [58]. S. Sharma et. al. focuses on three widely studied routing protocols for MANETs: AODV, DSR and DSDV. They evaluate the performance of AODV, DSR and DSDV on several key metrics such as PDR, End to End Delay, Throughput and Control Overhead. The study shows that while reactive protocols are better suited for dynamic networks due to their lower control overhead and adaptability, they suffer from higher latency and reduced throughput in larger networks, On the other hands proactive protocols provide low latency and immediate route availability but suffer from scalability issues due to high control overhead [59]. N. Yadav et. al. focused on three widely studied routing protocols for MANETs: AODV, DSR and DSDV. They evaluate the performance of AODV, DSR and DSDV on several key metrics such as PDR, End to End Delay, Throughput and Control Overhead. Reactive protocols, such as AODV and DSR, are shown to be more efficient in dynamic environments where node mobility is high. DSDV, as a proactive protocol, offers low latency communication because routes are always available when needed. In Addition, the authors suggest that future research should focus on improving the energy efficiency of routing protocols [60].

The literature review emphasizes the importance of selecting the appropriate MANET routing protocol based on particular network conditions and requirements. The Proactive protocols like DSDV and OLSR are advantageous for their route accessibility and throughput but face scalability and energy consumption issues. Reactive protocols such as AODV and DSR excel in dynamic environments with low control overhead but suffer route discovery delays and performance degradation in larger networks. Hybrid protocols offer a balanced approach, combining the strengths of both proactive and reactive strategies, but come with implementation complexities. We also see that most of the papers do not considering dense networks, whereas we consider a denser network with 350 nodes in our simulation scenario. We have considered three phases for our simulation by varying the number of nodes, varying pause times and varying physical network sizes.

Building on the insights and findings from previous research discussed in the literature review, we propose the following hypotheses to guide our evaluation of the performance of different MANET protocols under various simulation scenarios:

H1: DSR Performance in Dynamic Networks

In dynamic network environments with frequent topology changes and high node density, the DSR (Dynamic Source Routing) protocol will achieve the highest packet delivery ratio (PDR) and exhibit low control overhead due to its efficient route discovery and caching mechanisms. Previous studies have shown that DSR is effective in maintaining high PDR and minimizing control overhead, particularly in scenarios with high mobility. This efficiency stems from its on-demand route discovery process and ability to cache multiple routes to the same destination, which we aim to further evaluate in our dense network simulations.

H2: OLSR Performance in Static Networks

In static or moderately dynamic network environments with low node mobility and large network sizes, the OLSR (Optimized Link State Routing) protocol will maintain high throughput and low end-to-end delay due to its proactive nature of maintaining up-to-date routing tables. The literature indicates that proactive routing protocols like OLSR can ensure immediate route availability and low latency. However, this comes at the cost of higher control overhead, particularly in dynamic networks. Our simulation will explore OLSR's performance in static and large network scenarios to validate these findings.

H3: AODV Performance Degradation with Increasing Network Size

The performance of the AODV (Ad-hoc On-Demand Distance Vector) protocol will degrade significantly in larger network sizes, resulting in lower throughput and increased control overhead. Existing research highlights that AODV performs efficiently in smaller networks. However, as the network size increases, its reactive nature, which relies on broadcasting route requests, leads to higher control overhead and reduced throughput. This hypothesis will be tested under varying network sizes in our simulations.

H4: DSDV Performance in Static Environments

In static or low-mobility environments, the DSDV (Destination-Sequenced Distance Vector) protocol will achieve the highest throughput but exhibit high control overhead due to frequent routing table updates. The proactive nature of DSDV involves periodic updates to routing tables, which can be resource-intensive in dynamic environments. However, this characteristic also allows for high throughput in static networks where routes do not change frequently. Our study will assess DSDV's performance under varying pause times and network sizes to validate this behavior.

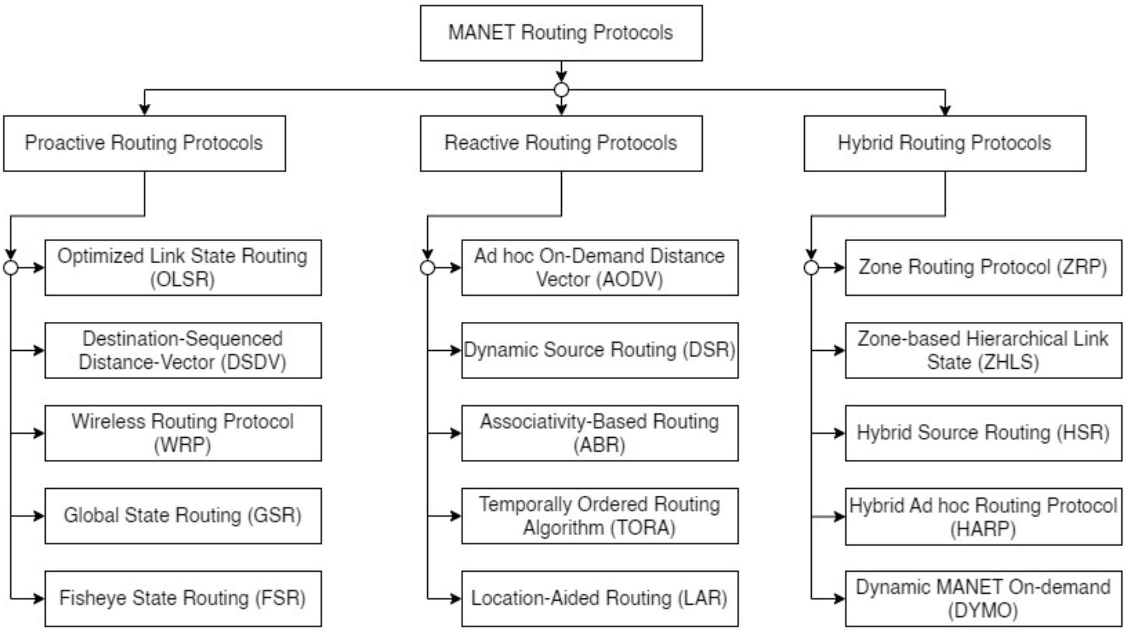


Figure 1. Shows a simple classification of the MANETs routing protocols

3. MANET ROUTING PROTOCOLS

Every node in a MANET is responsible for forwarding packets from the source node and determining its neighboring nodes in order to find the most efficient route to a destination node [61]. Upon the entry of a fresh node into the system, it initiates the transmission of a welcome message to all neighboring nodes and starts the process of acquiring knowledge [62]. Additionally, a database of routing tables is kept up to date by each node that contains information about the existing nodes in the network as well as the quantity of hops that are necessary to attain them [63]. There are different routing techniques for data forwarding and discovery in Mobile Ad-hoc Networks, categorized into three main types. Routing protocols that are proactive, such Optimized Link State Routing (OLSR), regularly update their routing databases, which introduces system overhead, but guarantees that paths are readily accessible with little halt [64]. These protocols outperform reactive ones because they constantly refresh their knowledge of the network, allowing immediate packet forwarding when needed. DSR and AODV are instances of reactive methods that create a path to the destination only in the event that a source node needs to send a packet [65]. This results in lower network overhead but slower route discovery. Zone Routing Protocol (ZRP) and other hybrid routing systems mix proactive and reactive routing tactics. They frequently update information about local neighbors, while information about distant nodes is updated on demand, similar to reactive protocols [66]. Figure 1 provides a straightforward classification of MANET routing protocols.

3.1. AODV Routing Protocol

Mobile hosts function as intermediate nodes in MANETs to forward packets via AODV which is reactive and ad-hoc [67]. Every node in AODV serves as a router and updates its local routing tables in response to packet generation or requests. A discovery process ensures that nodes remain connected to their neighbors. The time it takes to respond to fresh requests is extended due to the AODV detection process. When a node must locate the fastest path to the end point, it notifies its neighbors with a Route Request packet. With fewer trips to the destination, this technique raises node awareness. An intermediary node rebroadcasts the Route Request to all of its nearby nodes if it lacks a direct path to the end point [68]. An intermediary node notifies the source node of a Route Reply (RREP) when it finds a new path to the end point that satisfies the RREQ requirements [69]. Every intermediary node updates the modified data in their local routing table during the forwarding of RREQ and RREP packets. The sequence number of the target node, hop count, destination node, intermediate nodes and route entry expiration time address are all included in each routing table entry [70]. As soon as the starting node grabs the Route Reply packet, it is ready to begin data transmission. If the source node is beyond the Mobile Ad-hoc Networks coverage region at the time of the current route request, it may initiate a fresh path mapping procedure with a distinct demand ID. The AODV routing protocol workflow flowchart is demonstrated in Figure 2.

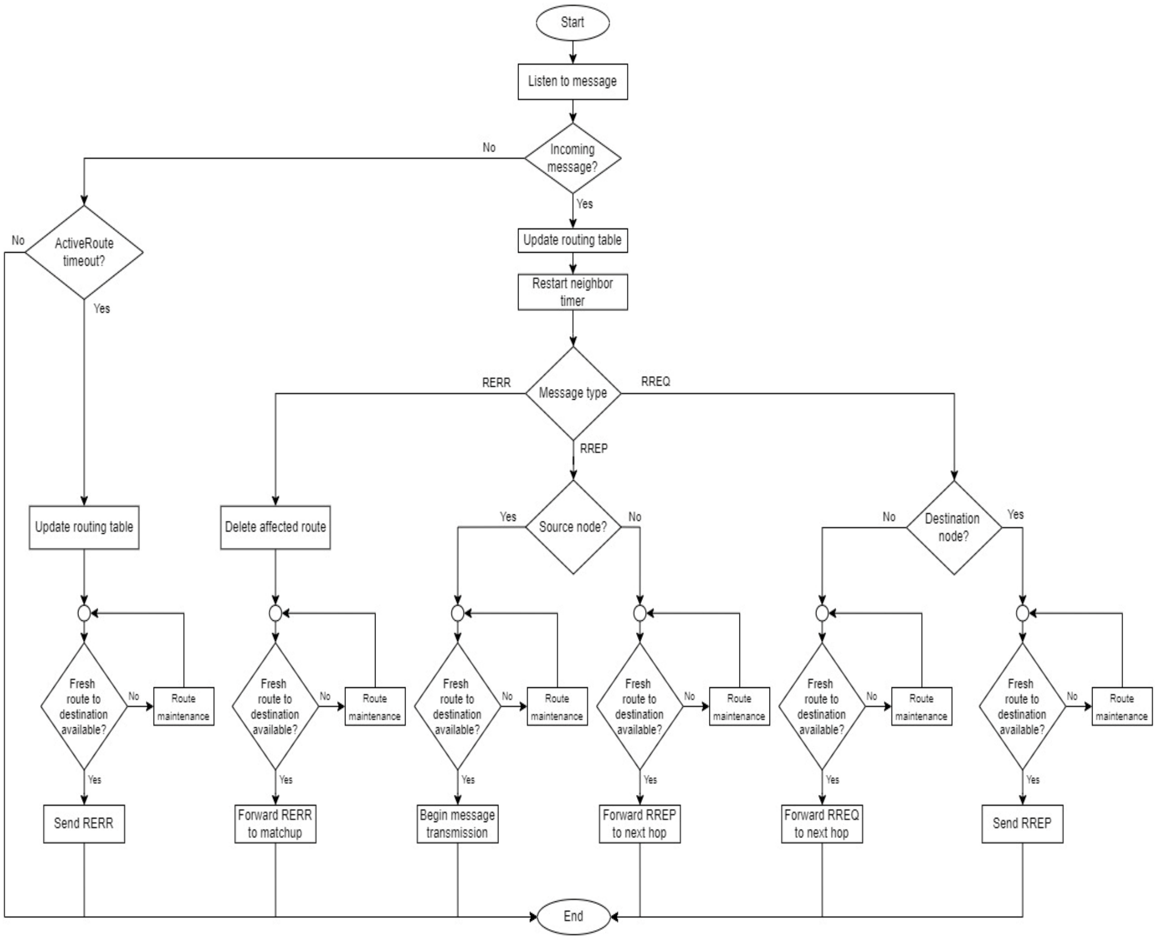


Figure 2. The workflow of processes of AODV protocol

3.2. DSR Routing Protocol

MANETs are intended for use with the extremely effective reactive routing system known as Dynamic Source Routing (DSR). Every data packet in DSR has a header that has all of the intermediary nodes IP addresses between destination nodes and the source [71]. The hops that must be made in order to get to the destination are listed in this heading. A source node in a DSR network can cache numerous routes to the same destination, and each node keeps a cache memory to hold routing information for all nodes inside the MANET. Compared to existing MANET routing protocols, this technique enables quicker data packet routing since it does away with the requirement for recurring packet transmissions, which lowers network overhead [72]. Route maintenance and route discovery are the two fundamental ways that DSR functions [73]. When a source node does not have the required routing information to arrive at the desired node, the route discovery process starts. To start the source node sends out a RREQ during the route discovery procedure message to any neighbor that is within wireless range. The route request identification, destination node identifier, source node identifier, and a list of all intermediary node addresses are all included in the RREQ message. When a cached route to a destination becomes invalid, route maintenance is initiated. The source node can try to use either begin a new route navigation procedure or use an alternative cached path to the destination to find alternate routes and update the cache if a link to the destination node is broken. The DSR protocol workflow flowchart is shown in Figure 3.

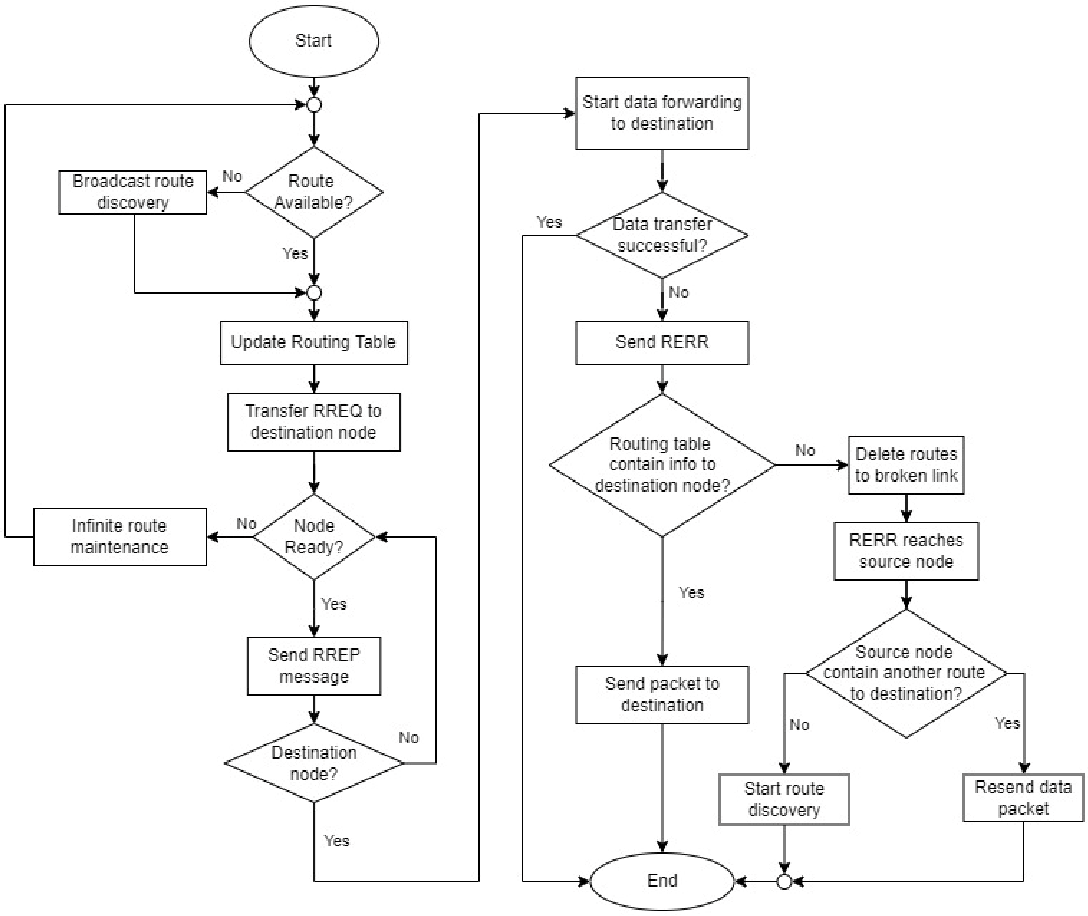


Figure 3. DSR routing protocol workflow flowchart

3.3. OLSR Routing Protocol

Through recurring control packet exchanges, the proactive routing system known as Optimized Link State Routing (OLSR) preserves the network topology [74], making sure that, when needed, there are paths to nearby nodes. By notifying more than a portion of the neighbors, OLSR reduces the data rate of control packets [75]. With bidirectional networks, Multipoint Relay (MPR) nodes are usually two hops away. By retransmitting broadcast messages, they receive, these MPR nodes cut down on redundant broadcasts. Within Mobile Ad hoc Networks, non-MPR nodes, process messages received but do not retransmit them (MANETs). Every node in OLSR sends out hello messages with information about its neighbors on a regular basis. Nodes can create a neighbor table by using this message to find out about their one-hop neighbors and link states [76]. Using hello message information, nodes also identify their formation of the MPR selector table using two-hop neighbors. Every node regularly sends another control message (TC) along with the hello messages in order to obtain a complete view of the network architecture and enhance scalability. The transmitters MPR selector list is included in TC messages, which enable nodes to modify their topology tables. Only when a change in the MPR table needs to be shared is a TC message sent, and there is a time limit between each TC transmission. A node changes its topology table by adding a new record or preserving an old one in response to a TC message. In Figure 4, the workflow of OLSR routing protocol approach is showed.

3.4. Destination sequenced distance vector

Every node in the hop-by-hop vector routing protocol known as DSDV transmits routing changes on a regular basis. Table-driven operation is employed, and the Bellman-Ford routing method is utilized. Every node in the network keeps assess the target nodes and the quantity of steps necessary in a routing table to get there. To keep track of delayed operations, a sequence number is included with every entry in the table. The possibility of a "count to infinity" problem is one drawback of continuous routing table updates. In order to fix this, DSDV updates the routing database using sequence numbers. Sequence numbers are an additional element that DSDV integrates, while still being similar to Distance Vector Routing. There is only one table that the protocol uses and maintains. The distance and corresponding sequence number of nearby nodes are included in this routing table. The sequence number rises with each change to the table. Every cycle, the routing database is updated to guarantee that packets are sent and received at the appropriate distance and sequence number. The DSDV protocol workflow processes are indicated in Figure 5.

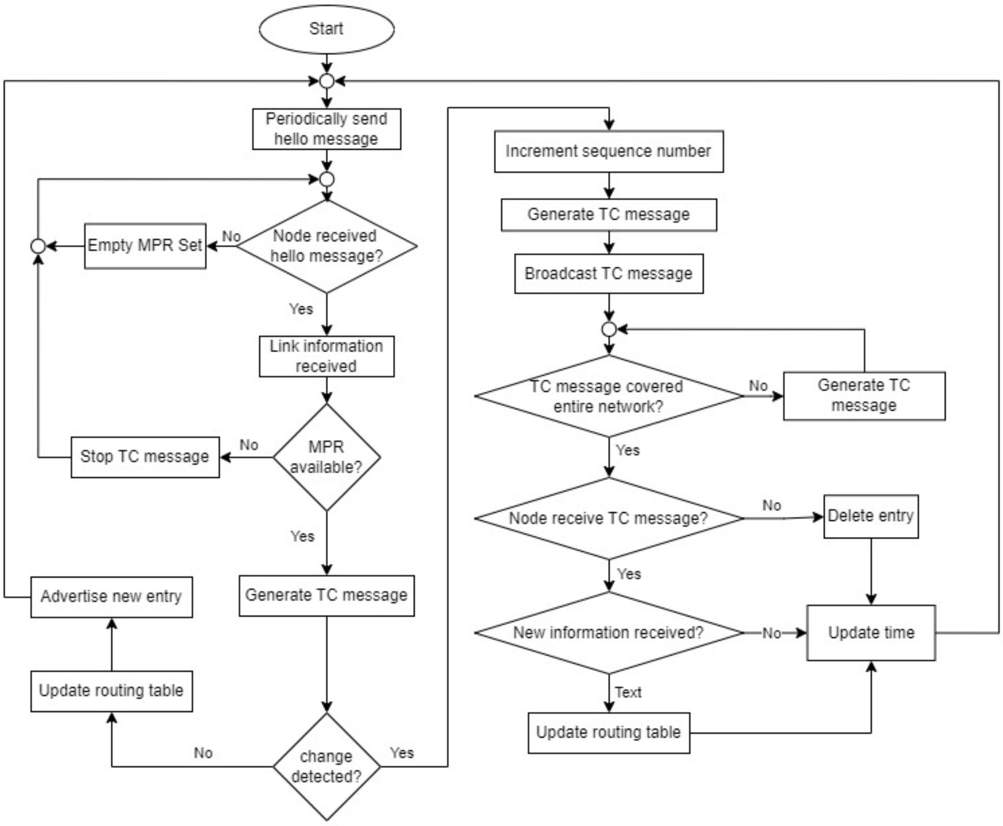


Figure 4. the OLSR protocol workflow diagram

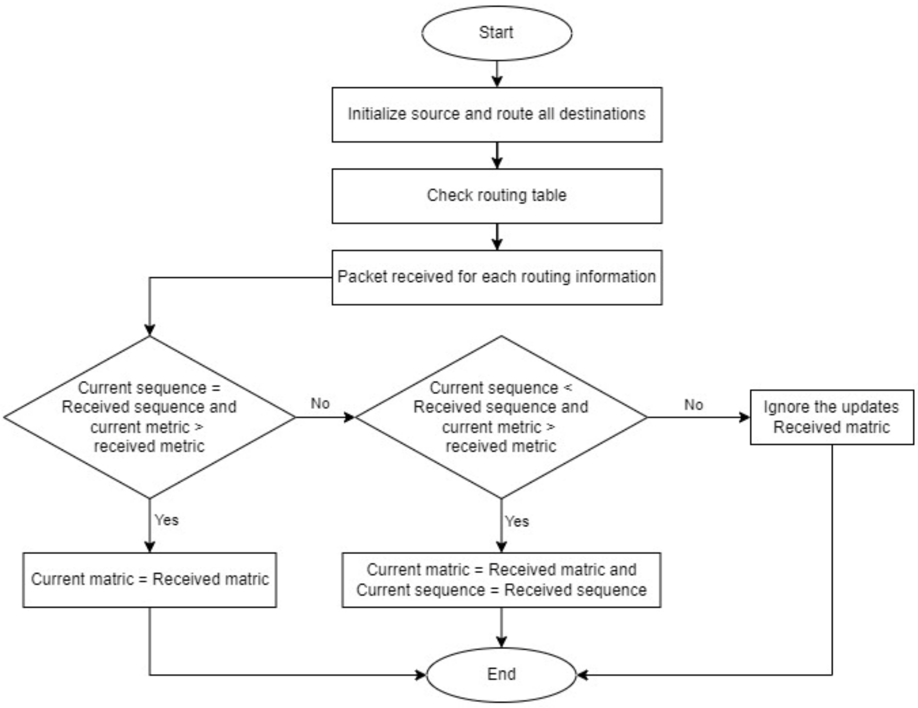


Figure 5. Workflow processes of DSDV protocol.

4. PERFORMANCE METRICES

Performance metrics are used to describe the network, which is significantly influenced by the routing algorithm in order to accomplish the desired Quality of Service (QoS). This paper considers the following metrics.

PDR ratio: PDR is the quantity of packets received divided by the total amount of packets sent. It may be determined using equation (1).

$$\text{PDR} = \frac{\text{Total amount of packets received}}{\text{Total amout of packets sent}} \quad (1)$$

Throughput: Throughput is the ratio of the total amount of data successfully delivered (in bits, bytes or packets) to the total time taken for the data to be delivered. Throughput refers to the mean rate at which messages are successfully delivered across a communication connection. Equation 2 computes the throughput in the following manner:

$$\text{Throughput} = \frac{\text{Total amount of data successfully delivered}}{\text{Total time taken for the data to be delivered}} \quad (2)$$

Control Overhead: The ratio refers to the proportion of control information sent compared to the actual data received at each node.

$$\text{Control Overhead} = \frac{\text{Total amount of control Information sent}}{\text{Total amount of actual data received}} \quad (3)$$

End-to-End Delay: The time it takes to send a packet through several nodes. Because delay is tied to time, it's in milliseconds. Equation (4) calculates average delay.

$$\text{Delay} = \frac{\text{Time packet received} - \text{Time packet sent}}{\text{total package received}} \quad (4)$$

5. RESULT AND DISCUSSION

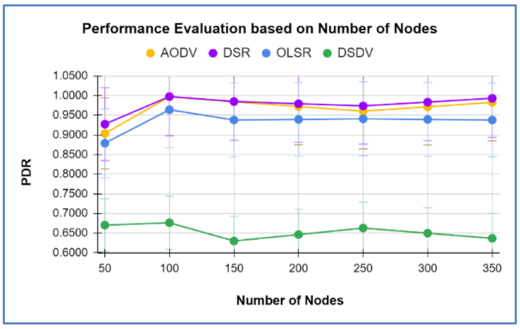
Performance analysis of this work is done through three phases firstly varying quantity of nodes, secondly varying pause duration and thirdly varying the network size. We investigate four routing strategies in this work: DSDV and OLSR, which are proactive, and AODV and DSR, which are reactive. Table 1 represents the parameter values of phase I, II and III respectively.

Table 1. Parameter values of Phase I, II and III

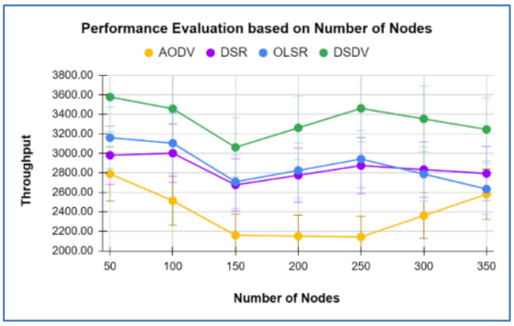
Parameter	Value		
	Phase I (Node)	**Phase II (Pause time)**	**Phase III (Network Size)**
Network Simulator	Network Simulator - 3	Network Simulator - 3	Network Simulator - 3
Simulation time	900 seconds	900 seconds	900 seconds
Simulation Area	300m × 300m	300m × 300m	250m × 250m, 375m × 375m, 500m × 500m, 625m × 625m, 750m × 750m, 875m × 875m, 1000m × 1000m,
Number of nodes	50, 100, 150, 200, 250, 300 and 350	200	200
Protocol used	AODV, DSR, OLSR, DSDV	AODV, DSR, OLSR, DSDV	AODV, DSR, OLSR, DSDV
Model	Random Way Point	Random Way Point	Random Way Point
Transport Layer Protocol	UDP	UDP	UDP
MAC Protocol	IEEE 802.11	IEEE 802.11	IEEE 802.11
Power Transmission	0.0015W	0.0015W	0.0015W
Packet Size	16 kilobyte/sec	16 kilobyte/sec	16 kilobyte/sec
Node speed (m/s)	10	10	10
Pause Time	0 seconds	50, 100, 150, 200, 250, 300 and 350 seconds	0 seconds

5.1. Phase I Varying the number of nodes

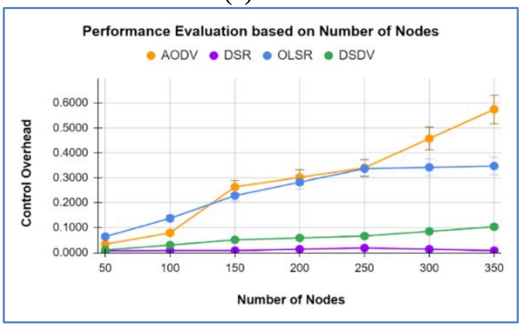
From 50 to 350 nodes are utilized in Phase I. We put the pause time to 0 seconds and the simulation area to 300X300 square meters. In simulation, 28 simulation runs for each protocol for different parameters. From Figure 6(a) we see that both DSR and AODV show high PDR, consistently above 0.95 for all node densities. DSR slightly outperforms AODV, especially noticeable at the 100-node mark where it reaches nearly 1.0. The slight outperformance of DSR over AODV at the 100-node mark is primarily due to its efficient route discovery and maintenance mechanisms, lower protocol overhead and effective use of route caches. OLSR performs slightly lower than AODV and DSR, maintaining a PDR above 0.90 but less than 0.95. OLSR's slightly lower compared to AODV and DSR can be attributed to its proactive nature, higher control message overhead, complexity in maintaining full routing tables, slower adaptation to topology changes and potential issues with multicast control message collisions. While OLSR ensures up-to-date routing information, the trade-offs in overhead and resource usage result in slightly lower PDR in comparison to the more dynamic and on-demand approaches of AODV and DSR. DSDV has the lowest PDR among the four protocols, ranging between 0.60 and 0.70. The PDR for DSDV shows more significant variations compared to other protocols, indicating less stability in its performance. DSDV is less efficient in highly dynamic environments where nodes frequently move or the network topology changes rapidly. The protocol struggles to maintain accurate routing information in such scenarios, leading to increased packet loss and lower PDR. From Figure 6(b) we see that DSDV has the highest throughput among all protocols, starting around 3600 units and gradually decreasing to about 3200 units as the quantity of nodes increases. This elevated and stable throughput indicates DSDV's efficient handling of data packets, especially in larger networks. OLSR maintains a high throughput, consistently staying between 3000 and 3200 units. The throughput is stable across different node densities, showing only slight variations. OLSR's proactive nature ensures that routes are always available, contributing to its high throughput performance. DSR shows moderate throughput, generally around 2800 units, with a slight dip as the number of nodes increases, particularly around 150 nodes. DSR's throughput performance is relatively stable but slightly lower than OLSR and DSDV, which can be attributed to its reactive nature. AODV has the lowest throughput among the four protocols, starting around 2800 units at 50 nodes and decreasing to around 2200 units as the number of nodes increases. The decreasing trend suggest that AODV's reactive routing mechanism struggles to maintain high throughput as the network size grows. Figure 6(c) we see that DSR has minimal control overhead in contrast with other protocols because DSR is an on-demand routing protocol, meaning that routes are established only when they are needed. This minimizes the amount of control traffic since route discovery processes are initiated only when source nodes must interact with nodes at their destination. The OLSR displays a gradual increase in control overhead, more moderate compared to AODV because OLSR is a proactive routing protocol, which means it always maintains up-to-date routes to all possible destinations. This requires periodic exchange of control messages to keep the routing tables current, resulting in a steady increase in control overhead as the network size grows. AODV exhibits a steady increase in control overhead as the number of nodes increases. AODV protocol starts with a low overhead at 50 nodes and rises to the highest among the four protocols at 350 nodes because AODV uses an on-demand route discovery process, which involves broadcasting Route Request (RREQ) messages to find a path to the destination. As the quantity of nodes escalates, the amount of RREQ messages that seek to be broadcasted and processed by intermediate nodes increases, leading to higher control overhead. The DSDV protocol starts with very low control overhead similar to DSR and experiences a slight increase in overhead with more nodes but remains low compared to AODV and OLSR.



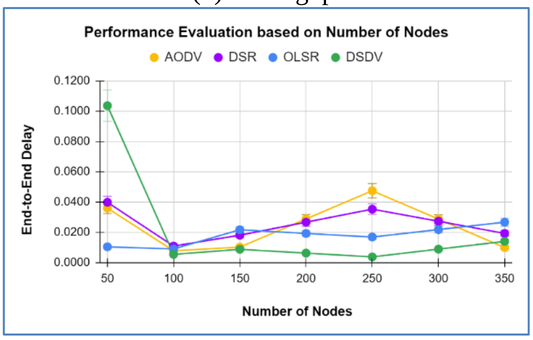
6(a) PDR



6(b) Throughput



6(c) Control Overhead



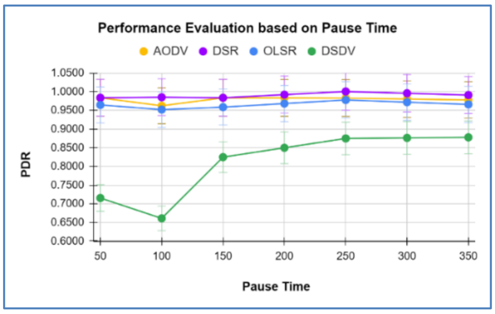
6(d) End-to-End Delay

Figure 6. Phase I Varying the number of nodes

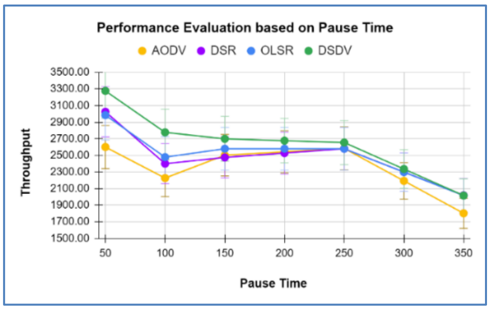
From Figure 6(d) we see that DSDV shows a very high end-to-end delay at 50 nodes, reaching around 0.12. This delay drastically decreases as the number of nodes increases and stabilizes at a low delay level similar to the other protocols beyond 100 nodes. This high initial delay could be due to the overhead of establishing routing tables in smaller networks. AODV exhibits relatively low and stable end-to-end delay across different node densities, with a slight increase at the 250-node mark. However, it quickly returns to a lower delay as the number of nodes increases. This indicates AODV’s efficiency in maintaining low latency in route discovery and maintenance. DSR maintains a consistently low end-to-end delay across all node densities, slightly increasing at 250-nodes but still remains under 0.04. This consistency highlights DSR’s ability to efficiently manage routes without introducing significant delays. OLSR shows the lowest and most stable end-to-end delay among all the protocols, remaining very close to zero across all node densities. As proactive protocol, OLSR’s constant updating of routes ensures that data packets experience minimal delay during transmission.

5.2. Phase II Varying the Pause Times

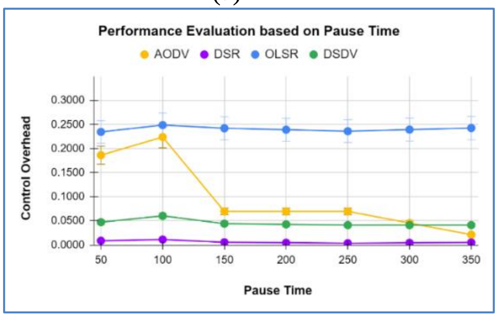
In this phase, we vary the pause time from 50 to 350 seconds. We also set the number of nodes to 200, which is fixed for this scenario and all the other parameters remain unchanged. From Figure 7(a) we see that DSR maintains a consistently high PDR close to 1.0 across all pause times, indicating excellent packet delivery performance regardless of the networks stability or mobility. AODV also shows high PDR values, slightly below DSR, remaining above 0.95 for all pause times. This consistency indicates reliable packet delivery but with a slight variation compared to DSR. OLSR performs similarly to AODV, with PDR values slightly above 0.95 and close to 1.0 across all pause times. This reflects OLSR’s efficiency in maintaining routes and delivering packets consistently. DSDV starts with a lower PDR at 0.7 for a pause time of 50, but it gradually increases to about 0.9 as the pause time increases to 350. The initial lower PDR could be due to the protocols overhead in maintaining and updating routing tables, which stabilizes as the network becomes less dynamic with higher pause times. From Figure 7(b) we see that DSDV exhibits the highest throughput among the protocols, starting at around 3300 units at 50 pause time and gradually decreasing to approximately 2300 units at 350 pause time. The high throughput is indicative of DSDV’s efficient data packet handling, especially in dynamic conditions with lower pause times. OLSR maintains high throughput, starting at around 3100 units at 50 pause time and gradually decreasing to around 2100 units at 350 pause time. The consistent performance across varying pause times highlights OLSR’s effectiveness in maintaining routes and ensuring high data transfer rates. DSR starts with a throughput close to 2900 units at 50 pause time, which decreases to around 2000 units at 350 pause time. The performance is relatively stable but slightly lower than DSDV and OLSR, reflecting its reactive nature which may introduce some delays affecting throughput. AODV shows the lowest throughput, starting at around 2700 units at 50 pause time and decreasing to approximately 1800 units at 350 pause time. The declining trend suggests that AODV’s reactive route discovery process might not be as efficient in maintaining high throughput, especially as the network becomes more static.



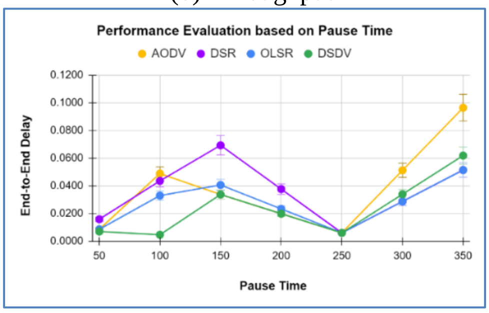
7(a) PDR



7(b) Throughput



7(c) Control Overhead



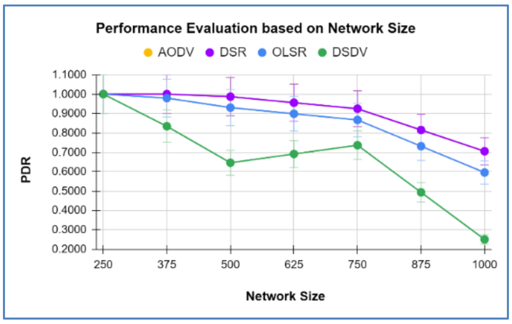
7(d) End-to-End Delay

Figure 7. Phase II Varying the Pause Time

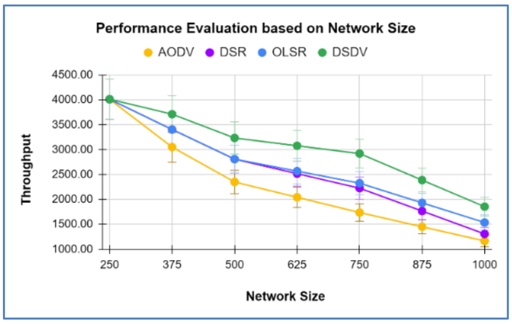
From Fig 7(c) we see that OLSR consistently shows highest control overhead across all pause times, maintaining a level around 0.25 to 0.28. This high overhead is due to OLSR's proactive nature, where it continuously exchanges control messages to maintain up-to-date routing tables, regardless of whether there is data to send. This results in substantial overhead, particularly noticeable in scenarios with varying pause times. AODV starts with a relatively high control overhead at around 0.2 for lower pause times (50-100) and significantly drops to about 0.1 at 150 pause time, stabilizing around this value up to 350 pause time. The high initial overhead can be attributed to the frequent route discoveries in more lower pause times, which reduce as the network becomes more stable at higher pause times, leading to decreased control message exchange. DSDV shows a moderate control overhead, slightly higher than DSR but lower than AODV and OLSR, starting around 0.1 and decreasing to around 0.05 as pause time increases. The proactive nature of DSDV, with periodic updates and triggered updates for significant topology changes, contributes to this overhead. However, it is less than OLSR due to less frequent update intervals. DSR consistently has the lowest control overhead across all pause times, maintaining a value close to zero. DSR only generates control messages when routes are needed or broken, resulting in minimal overhead, especially in networks with higher pause times where route discoveries are less frequent. From Figure 7(d) we see that DSDV consistently shows the lowest delay across all pause duration, maintaining value close to zero. This indicates that DSDV is highly efficient in delivering packets quickly once routes are established, benefiting from its proactive nature. OLSR exhibits low and stable end-to-end delay, similar to DSDV, but with slightly higher values. OLSR must compute and maintain multiple routes using link state information, which involves more frequent and detailed updates. The computational overhead associated with these updates can introduce slight delays, resulting in higher end-to-end delay contrasted to DSDV. DSR shows moderate end-to-end delay with noticeable peaks at lower pause times (100 and 150), reaching values around 0.06. The delay decreases at 200 pause time but increases again at 350. The variability in delay is due to DSR's reactive nature, where route discoveries can introduce higher delays, particularly in dynamic conditions with lower pause times. AODV starts with low delay values similar to DSDV and OLSR but shows a significant increase at 350 pause time, reaching around 0.10. The increase in delay at higher pause times suggests challenges in route maintenance and discovery as the network becomes more static.

5.3. Phase III Varying Network Size

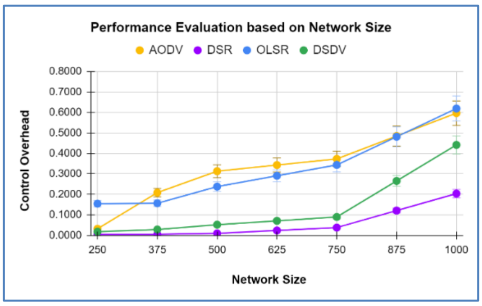
In this phase, we vary the network size as follows 250m × 250m, 375m × 375m, 500m × 500m, 625m × 625m, 750m × 750m, 875m × 875m and 1000m × 1000m. From Figure 8(a) we see that DSR demonstrates the highest and most stable PDR, making it suitable for larger networks where reliable packet delivery is critical.



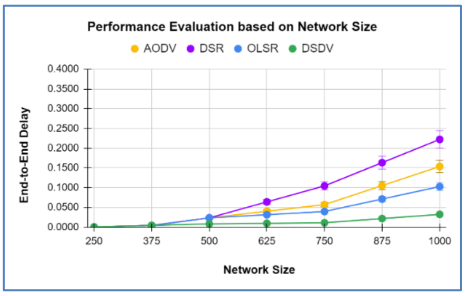
8(a) PDR



8(b) Throughput



8(c) Control Overhead



8(d) End-to-End Delay

Figure 8. Phase III Varying the Network Size

Table 2. Detail result analysis values of phase I, II and III

	Phase I Varying Number of Nodes					Phase II Varying Pause Time					Phase III Varying Network Size				
	Number of Nodes	**AODV**	**DSR**	**OLSR**	**DSDV**	**Pause Time**	**AODV**	**DSR**	**OLSR**	**DSDV**	**Network Size**	**AODV**	**DSR**	**OLSR**	**DSDV**
PDR	50	0.9035	0.9274	0.8788	0.6702	50	0.9838	0.9838	0.9647	0.7154	250	1.0014	1.0014	1.0014	1.0014
	100	0.9970	0.9977	0.9641	0.6762	100	0.9625	0.9852	0.9522	0.6610	375	1.0014	1.0014	0.9807	0.8352
	150	0.9842	0.9850	0.9379	0.6299	150	0.9838	0.9838	0.9588	0.8250	500	0.9881	0.9881	0.9317	0.6467
	200	0.9723	0.9794	0.9394	0.6463	200	0.9834	0.9922	0.9683	0.8500	625	0.9569	0.9569	0.8998	0.6920
	250	0.9603	0.9738	0.9409	0.6628	250	0.9830	1.0007	0.9779	0.8750	750	0.9257	0.9257	0.8679	0.7372
	300	0.9715	0.9835	0.9394	0.6497	300	0.9805	0.9959	0.9720	0.8764	875	0.8159	0.8159	0.7320	0.4938
	350	0.9828	0.9932	0.9379	0.6366	350	0.9779	0.9911	0.9661	0.8779	1000	0.7061	0.7061	0.5962	0.2504
Throughput	50	2789.3	2980.5	3161.0	3578.7	50	2600.3	3024.9	2984.1	3276.2	250	4012.9	4012.9	4012.9	4012.9
	100	2513.2	3001.7	3104.4	3458.4	100	2226.7	2400.0	2478.1	2776.9	375	3051.8	3405.6	3405.6	3712.2
	150	2159.2	2676.1	2707.9	3061.9	150	2501.8	2474.7	2580.0	2698.8	500	2350.2	2810.1	2810.1	3234.6
	200	2150.4	2775.2	2824.7	3261.9	200	2542.6	2527.3	2580.0	2676.7	625	2043.6	2518.2	2568.3	3078.4
	250	2141.5	2874.3	2941.5	3461.9	250	2583.3	2580.0	2580.0	2654.7	750	1737.0	2226.4	2326.6	2922.1
	300	2361.0	2833.6	2787.6	3353.9	300	2192.8	2299.8	2298.1	2335.4	875	1451.0	1766.5	1931.6	2388.5
	350	2580.5	2792.9	2633.6	3246.0	350	1802.2	2019.6	2016.2	2016.2	1000	1165.0	1306.6	1536.5	1854.9
Control Overhead	50	0.0337	0.0069	0.0641	0.0104	50	0.1862	0.0086	0.2345	0.0472	250	0.0317	0.0047	0.1541	0.0176
	100	0.0792	0.0081	0.1375	0.0303	100	0.2238	0.0111	0.2487	0.0604	375	0.2082	0.0047	0.1564	0.0282
	150	0.2634	0.0081	0.2284	0.0512	150	0.0695	0.0055	0.2421	0.0441	500	0.3129	0.0094	0.2376	0.0517
	200	0.3018	0.0134	0.2826	0.0588	200	0.0695	0.0045	0.2390	0.0426	625	0.3429	0.0235	0.2905	0.0705
	250	0.3403	0.0186	0.3368	0.0664	250	0.0695	0.0035	0.2360	0.0411	750	0.3729	0.0376	0.3435	0.0894
	300	0.4574	0.0134	0.3420	0.0850	300	0.0454	0.0043	0.2393	0.0411	875	0.4847	0.1205	0.4811	0.2652
	350	0.5745	0.0081	0.3473	0.1037	350	0.0213	0.0050	0.2426	0.0411	1000	0.5964	0.2035	0.6188	0.4411
End-to-End Delay	50	0.0358	0.0397	0.0102	0.1035	50	0.0084	0.0157	0.0084	0.0068	250	0	0	0.0004	0.0004
	100	0.0076	0.0107	0.0088	0.0052	100	0.0488	0.0435	0.0328	0.0045	375	0.0042	0.0042	0.0042	0.0042
	150	0.0100	0.0179	0.0215	0.0086	150	0.0336	0.0692	0.0405	0.0336	500	0.0233	0.0233	0.0233	0.0080
	200	0.0287	0.0265	0.0191	0.0061	200	0.0197	0.0375	0.0232	0.0197	625	0.0400	0.0637	0.0313	0.0095
	250	0.0473	0.0351	0.0167	0.0035	250	0.0059	0.0059	0.0059	0.0059	750	0.0567	0.1042	0.0394	0.0110
	300	0.0285	0.0271	0.0216	0.0087	300	0.0511	0.0286	0.0286	0.0338	875	0.1050	0.1631	0.0709	0.0216
	350	0.0098	0.0191	0.0265	0.0138	350	0.0964	0.0513	0.0513	0.0618	1000	0.1533	0.2220	0.1025	0.0322

OLSR maintains relatively high PDR, benefiting from its proactive routing but still facing challenges in larger networks due to increased overhead. AODV's performance declines more sharply with increased network size, indicating issues with scaling and increased packet loss in larger networks. DSDV shows the lowest PDR, struggling significantly with larger network sizes due to its high control message overhead and frequent updates. The increase in control overhead for proactive protocols like OLSR and DSDV in larger networks leads to congestion, reducing PDR. Reactive protocols like DSR and AODV handle route discoveries on demand, but AODV's efficiency decreases with network size due to frequent route discoveries and maintenance. From Figure 8(b) we see that DSDV shows the highest throughput among the protocols, starting around 4000 units at 250 sqm and gradually decreasing to about 2000 units at 1000 sqm. DSDV's proactive nature ensures that routing information is always available, reducing the latency involved in route discoveries. This constant availability of routes allows for more continuous and efficient data packet transmission resulting in higher throughput.

OLSR maintains high throughput, starting at approximately 3700 units at 250 sqm and decreasing to around 1600 units at 1000 sqm. OLSR, like DSDV, is a proactive routing protocol that frequently updates routing tables to reflect the current network topology. This ensures that data packets have ready routes, although the control message overhead required to maintain these updates slightly reduces throughput as the network size increases. DSR provides moderate throughput, but the performance drops as the network size increases due to the overhead of on-demand route discoveries. AODV has the lowest throughput, significantly impacted by its reactive nature, which incurs high overhead for route management in larger networks. From Figure 8(c) we see that OLSR exhibits the highest control overhead across all network sizes, starting at about 0.2 at 250 sqm and increasing to around 0.65 at 1000 sqm due to the exponential growth in the volume of control messages required to maintain accurate routing information in larger and denser networks. AODV shows a moderate control overhead, starting around 0.15 at 250 sqm and rising to about 0.6 at 1000 sqm. The increasing trend reflects the overhead associated with its reactive route discovery process, which becomes more significant as the network size grows. DSDV has a lower control overhead compared to OLSR and AODV, starting around 0.1 at 250 sqm and increasing to about 0.4 at 1000 sqm. DSR exhibits the lowest control overhead due to DSR's on-demand route discovery mechanism, which generates control messages only when routes are needed, resulting in less frequent control message exchanges. From Figure 8(d) we see that there is a slight increase in delay for OLSR compared to DSDV is due to the additional control message overhead required to maintain detailed link state information. Both DSDV and OLSR maintain up-to-date routes, ensuring quick packet forwarding and minimal delay. AODV and DSR suffer from increased delays due to the time required to establish routes on demand. This task becomes more time consuming as network size rises, leading to higher end-to-end delays, especially discernible for DSR. DSR's notable increase in delay highlights its challenges in boosting efficiently to larger networks, where frequent route discoveries and repairs become crucial. Table 2 represents detail result analysis values of phase I, II and III and Table 3 represents the performance evaluation summary of the above work.

Table 3. Represents the performance evaluation summary of the above work

Metric	DSDV	OLSR	DSR	AODV
PDR	Maintains stability in static networks, shows gradual improvements with increasing pause times	High and consistent PDR, slightly below DSR but reliable	Consistently high PDR across varying network conditions	High PDR, slightly below DSR but still reliable
Throughput	Highest throughput across all scenarios, efficient data packet handling	High throughput, reliable performance with minimal variations	Moderate throughput, stable but slightly lower than proactive protocols	Lowest throughput, steady decline with increasing network size
Control Overhead	Starts low and remains relatively low compared to OLSR and AODV	Moderate increase, maintains steady overhead levels	Consistently minimal control overhead	Moderate to high, starts low but increases significantly with network size
End-to-End Delay	Consistently low delay, particularly efficient in larger networks	Low and stable end-to-end delay, slightly higher than DSDV	Moderate delay with some variability, efficient in smaller networks	Relatively low delay, increases slightly with network size

The performance evaluation highlights the strengths and weaknesses of each routing protocol:

- DSDV excels in throughput and end-to-end delay, particularly in larger and static networks, but struggles with PDR and control overhead in dynamic environments (Meet the condition of H4).
- OLSR offers reliable performance with high PDR and low delay, though it incurs the highest control overhead (Meet the condition of H2).
- DSR provides the highest PDR and minimal control overhead, making it effective for dynamic networks, but it suffers from higher end-to-end delay (Meet the condition of H1).
- AODV represents good initial performance with high PDR and low delay in smaller networks, but its performance degrades sharply with increasing network size due to high control overhead and lower throughput (Meet the condition of H3).

To demonstrate the efficiency of our results, we will also compare them with other papers. Table 4 represents a brief comparison report using our work along with those of Mohapatra [58], Sharma [59], Yadav [60], Srijan [17] and Shailesh [20].

Table 4. represents a brief comparison report using our work along with those of Mohapatra [58], Sharma [59], Yadav [60], Srijan [17] and Shailesh [20]

Protocol	Metric	Scenario	Our Work	Mohapatra [58]	Sharma [59]	Yadav [60]	Srijan [17]	Shailesh [20]
DSR	PDR	High Node Density, 0s Pause Time	High (0.95–0.99)	Moderate (0.85–0.90)	High (0.92–0.96)	High (0.90–0.94)	Moderate (0.88–0.92)	High (0.93–0.97)
OLSR	Throughput	200 Nodes, Large Network Size	High (2800–3200 kbps)	High (2500–3000 kbps)	High (2700–3100 kbps)	Moderate (2200–2500 kbps)	High (2900–3200 kbps)	High (3000–3300 kbps)
AODV	Control Overhead	Increasing Network Size	Moderate to High (0.30–0.60)	High (0.50–0.70)	Moderate (0.20–0.45)	Moderate (0.30–0.50)	Low to Moderate (0.15–0.35)	Moderate (0.25–0.40)
DSDV	End-to-End Delay	Static Environment, Low Mobility	Low (0.01–0.03)	Low (0.02–0.05)	Low to Moderate (0.03–0.06)	Moderate (0.04–0.08)	Low (0.01–0.02)	Low (0.02–0.04)

From this comparison, both our results and Shailesh [58] show a high PDR for DSR in dense networks, consistent with Sharma [59] and slightly outperforming Mohapatra [58] and Yadav [60]. Srijan [17] reports a moderate PDR for DSR, suggesting varied performance under different conditions. Our work, along with Srijan [17], and Shailesh [20] reports high throughput for OLSR, aligning with the findings of Mohapatra [58] and Sharma [59]. However, Yadav [60] observed slightly lower throughput in larger network sizes. AODV's control overhead varies significantly; both our results and Mohapatra [58] reported moderate to high control overhead, while Shailesh [20] and Srijan [17] found it to be lower, indicating possible improvements or different network conditions. Both our results and Srijan [17] report low end-to-end delay for DSDV, consistent with Shailesh [20]. Mohapatra [58] and Sharma [59] also observed low delays, although Yadav [60] noted a slight increase in delay in more dynamic scenarios.

Our work emphasizes the differences and addresses the gaps in comparison efforts with Mohapatra [58]), Sharma [59], Yadav [60], Srijan [17], and Shailesh [20] through the following key aspects. Earlier studies like Mohapatra [58] and Sharma [59] primarily focused on small to medium-sized networks, typically using 30 to 100 nodes. Yadav [60] expanded to 150 nodes, while Srijan [17] and Shailesh [20] considered up to 200 nodes. Our paper fills this gap by conducting simulations in larger and denser network scenarios, considering up to 350 nodes. This approach provides a more realistic evaluation of routing protocols in environments similar to real-world applications, such as urban vehicular networks or emergency response systems. Earlier works, including those by Mohapatra [58], Sharma [59], Yadav [60], and Al-Nasir [19] predominantly utilized NS-2 for their simulations. Our study uses NS-3. By leveraging NS-3, our paper offers more reliable and accurate simulation results, capturing the complexities of network behavior in large-scale and dynamic environments, which previous NS-2 based studies could not adequately represent.

While studies by Mohapatra [58] and Sharma [59] focused on limited network conditions, such as fixed node density or static mobility models, and Srijan [17] and Shailesh [20] primarily examined the protocols under specific conditions, they did not perform a comprehensive, multi-dimensional analysis. Our paper adopts a three-phase evaluation approach that includes varying node densities, pause times, and network sizes. This detailed, multi-phase analysis provides a holistic view of each protocol's performance, identifying their strengths and weaknesses across a broad range of network dynamics. Although previous studies like Sharma [59] and Yadav [60] briefly touched on control overhead, they did not delve deeply into how this factor changes with increasing network size and mobility. Our paper places a significant emphasis on the control overhead of routing protocols, especially in high-density and large-scale networks. It explores how the overhead impacts network performance, particularly in terms of scalability and energy efficiency, areas that were not fully explored by Mohapatra [58] or Shailesh [20].

6. CONCLUSION

In this work we assessed the efficiency of four key MANET protocols DSR, AODV, OLSR and DSDV using distinct performance measures such as PDR, throughput, control overhead and end-to-end delay under diverse conditions including varying the number of nodes, varying pause times and varying physical network sizes. We found that DSR protocol has the highest average PDR, specially under heavy traffic, making it suited for denser networks. DSR protocols beat other protocols for network sizes under 625 sqm. If the network size exceeds 625 sqm and PDR and throughput are essential specs, then OLSR protocol is best for high mobility. DSDV excels in static and moderately dynamic environments with high throughput and low delay but struggles with PDR and control overhead in highly dynamic settings. AODV is effective in smaller networks, but its performance degrades with increased network size due to high control overhead and lower throughput. In future work, we want to use these achievements to create a protocol that can offer data integrity and delivery in highly unpredictable mobility networks. Our attention will also be on analyzing energy indicators as the cost function for routing in these protocols in order to improve quality of service applications.

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