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Effects of Control-Messages on (AODV & DSR) Protocols of VANETs: A Comparison and Results Simulation

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ABSTRACT: A VANET (as a class of MANET) which is formed by vehicles communication, links moving nodes (vehicles) and infrastructure for intelligent transportation solutions. Dynamic Source Routing (DSR) and Ad-Hoc On-Demand Distance Vector (AODV) are essential for data transfer in these dynamic networks. However, control message exchange greatly impacts these protocols' performance, which impacts network scalability, latency, and packet delivery efficiency. This study examines how control messages overhead affect VANET AODV and DSR protocol efficiency in various mobility situations and traffic volumes. Comprehensive simulations analyze packet delivery ratio, end-to-end delay, and routing overhead. Our findings suggest the use of DSR as a protocol evaluated for comparative analysis (low-density networks) with reduced control overhead while AODV is more adaptable in (high-mobility networks), depending on control message frequency. This work analysis and investigates the impact of control messages overhead on VANET routing protocols (AODV – DSR) for real-world vehicles enhancing efficiency and reliability with simulations under varying network sizes, number of sources, and pause times.

Keywords: VANETs, AODV Protocol, DSR Protocol, Control Messages, Routing Overhead

1. INTRODUCTION

VANETs, describes communications among (vehicles/cars) as well as vehicles to road side infrastructure (V2V / V2I), are crucial to current ITS. These networks provide traffic related, and accident prevention data quickly and reliably. VANETs' intermittent connection, changeable topology, and variable node density make routing protocol difficult [1].

VANET routing protocols link source and destination nodes. The most studied protocols are Dynamic Source Routing (DSR) and Ad-Hoc On-Demand Distance Vector (AODV), which generate routes only when required. AODV employs routing tables and control messages like RREQ and RREP, whereas DSR puts the whole route in the packet header. While different, control messages are necessary for route discovery and maintenance in both protocols, which may impact network performance route identification and maintenance require control message exchange, which may degrade network performance in high-density or mobility contexts [2]. This study addresses the gap of systematically analyze of the impact of control message overhead under varying network sizes by providing a comparative simulation-based evaluation of these protocols. Control messaging may raise VANET energy use, packet delivery ratios, and latency, a serious problem. Understand how control signals impact AODV and DSR to optimize them for real-world vehicle conditions.

It studies how control messages impact VANET-based AODV and DSR protocol efficiency. Simulations assess packet delivery ratio, end-to-end latency, and routing overhead in response to mobility and traffic density. Our analysis illuminates these protocols' strengths and weaknesses to assist VANETs implement and improve them. As a suggested future work, in addition to control message analysis, the evaluation of packet delivery ratio (PDR) and end-to-end delay for different scenarios and figures illustrations for each scenario would explain (while DSR generates fewer control messages, it exhibits higher end-to-end delay in larger networks, whereas AoDV maintain more stable PDR across varying network sizes [3].

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The below explanatory list summarizes the key characteristics of AODV vs. DSR:

Feature	**AODV**	**DSR**
Routing Type	On-demand (reactive)	On-demand (reactive)
Route Discovery	Uses RREQ/RREP messages	Uses RREQ/RREP with source routing
Routing Table / Cache	Maintains routing tables	Uses route cache
Control Message Overhead	Moderate	Low in small networks, higher in large networks
Scalability	Suitable for larger networks	Performs well in smaller networks
End-to-End Delay	Lower in larger networks	Can be higher in larger networks.

2. RELATED WORKS

Different routing techniques that increase performance in demanding and dynamic contexts have been researched due to Vehicular Ad-Hoc Network advances. Due to their flexibility and effectiveness, mobile network on-demand routing solutions like AODV and DSR have been studied. The performance impact of control messages is crucial.

Too many research has studied AODV and DSR's VANET performance. Kumar et al. (2022) found that AODV's efficient route-finding method beats DSR in high-mobility urban and highway settings. Sparse networks benefit from DSR's reduced routing cost. Ali et al. (2021) evaluated these protocols' scalability and found that AODV's excessive control messages may delay dense networks and that DSR's source routing mechanism minimizes overhead but struggles to keep up with frequent topology changes [4,5].

Routing protocols and control messages have been studied extensively recently. Sharma et al. (2023) propose an improved AODV protocol that reduces control message flooding, packet delivery ratio, and end-to-end delay by using probabilistic broadcasting. Zhang et al. (2022) introduced an adaptive control message mechanism for DSR to increase performance in dynamic VANETs. Route discovery packet frequency is constantly adjusted based on network density [6].

New VANET research subjects include optimizing routing protocols using machine learning and AI. Li et al. (2023) developed a reinforcement learning-based AODV variant that forecasts link stability and minimizes control message overhead for urban VANETs. A hybrid technique using machine learning to integrate AODV and DSR features is proposed by Gupta et al. (2022). This protocol balances control message overhead with route finding performance.

Recent developments have not clarified how traffic density and mobility effect control message overhead-protocol performance trade-offs. This research examines control messages' effects on AODV and DSR to optimize them for real-world VANET systems [7,8].

3. ON-DEMAND ROUTING PROTOCOLS: OVERVIEW

The routing systems (on demand) construct routes only when needed. VANETs and other dynamic networks benefit from these protocols. For limited resources and high mobility, on-demand protocols are better than proactive ones since they discover routes per-request, decreasing overhead.

AODV and DSR are two popular on-demand routing methods. AODV sends Route Request (RREQ) messages to discover routes. The destination sends a Route Reply (RREP) after finding a route, and intermediate nodes update routing entries to transport data packets. AODV's Route Error (RERR) messages prevent loops and optimize route maintenance [9].

DSR uses source routing and contains the source-to-destination route in the packet header. The destination sends RREQ messages a path Reply (RREP) containing the whole path for DSR route finding. DSR saves memory by eliminating routing tables, but its source routing reliance may increase packet size and inefficiency in large networks.

Control messages help both systems identify and maintain pathways, which may be problematic in densely crowded areas. Understand protocol trade-offs and limit message consumption to boost VANET performance [10].

3.1 Dynamic Source Routing (DSR) Protocol

VANETs and other multi-hop wireless ad hoc networks use DSR for on-demand routing. Its trademark is source routing, which includes the whole route from source to destination in the packet header. Since it doesn't update routing tables with intermediary nodes, DSR is better for low-resource networks and uses less memory.

Route Discovery and Maintenance are DSR's key steps. At Route Discovery, the source node sends a Route Request (RREQ) message to its neighbors if it has no route to the end point (destination). Each intermediary node adds its address to the RREQ packet before sending. The destination sends an RREP with the full route back to the source after receiving the RREQ [10,11]. Once channel formed, source transmits data packet.

DSR maintains communication routes. A node may send a Route Error (RERR) message to the source to start a fresh Route Discovery process if mobility or node failure breaks the connection. DSR allows nodes to cache several routes to a target, simplifying route discovery.

Due to its low routing change frequency, DSR has little control overhead in sparse networks. Long or often changing source paths in dense or mobile networks may increase packet sizes and compromise performance. Route Discovery RREQ message floods may cause excessive overhead on overcrowded networks [12].

DSR's have limitations in highly dynamic and large-scale VANET scenarios. Control message frequency and efficiency are critical to VANET communication.

- Control Packets of DSR Protocol

Dynamic Source Routing control packets establish and maintain VANET communication channels. These control packets find and maintain dependable data delivery paths in changing network settings. Route System Request, Route Reply, and Route Error are DSR's main control packets.

Route Request (RREQ)

A source node sends an RREQ packet to another. The request ID, source, and destination addresses reach all nearby nodes. Each intermediary node adds its address to the packet before broadcasting after receiving the RREQ. Should the RREQ fail to reach its target or a node, the procedure stops. RREQ packet node addresses may produce the whole route.

Route Reply (RREP)

RREP packets may be sent by any intermediate node with a cached route or the ultimate destination. It describes the sender-to-receiver path using RREQ packet data. The source node receives the RREP backwards to utilize this route for future data transfers [12].

Route Error (RERR)

When a connection along the active route becomes unavailable, the source node is notified via the RERR packet. An intermediate node will notify the source with an RERR packet that lists the destinations that are unreachable if it detects a connection failure, which might be caused by node mobility or failure. Once the source node receives the RERR, it deletes the incorrect route from its cache and, if needed, starts a new Route Discovery process.

Although they increase DSR's cost, control packets are necessary for protocol operation. RREQ packets during Route Discovery may cause network congestion, especially in busy or mobile networks. Sending RERR packets often in dynamic situations may reduce network efficiency and latency. Optimizing control packet use in VANETs improves DSR performance [13,14].

3.2 Ad-Hoc On-Demand Distance Vector (AODV) Routing Protocol

Ad-Hoc On-Demand Distance Vector (AODV) is a common VANET and mobile ad hoc network on-demand routing method. AODV's route building method reduces overhead and excels in topology-changing systems. It differs from table-driven protocols.

Route Discovery and Route Maintenance are AODV's major approaches. A node without a viable route to its destination sends a packet of Route Request (RREQ) to its neighbors during Route Discovery. An intermediate node rebroadcasts a packet after establishing a source route after receiving an RREQ. After reaching its destination or an intermediate node that changed its route, the RREQ will transmit a Route Reply (RREP) packet back along the opposite path to its origin. This network's intermediate nodes provide forward paths to the destination for data transfer.

Active route validity is assured by AODV Route Maintenance. If a link breaks due to node mobility or failure, the upstream node sends a Route Error (RERR) message. If the route is needed, the packet is delivered back to the source, which restarts Route Discovery. AODV also uses sequence numbers to keep routing information updated and loop-free [15].

The ability of AODV's to quickly adapt to network changes is useful for high-mobility systems like VANETs. In dense networks with frequent topology changes, the protocol's control packet reliance (RREQ, RREP, and RERR) may be costly. However, many favor AODV for its route management, scalability, and simplicity.

- The Route Discovery Procedure: Messages of control of AODV

The discovery of route in AODV uses RREQ, RREP, and RERR as control messages. These messages help create and maintain routes in VANETs and other dynamic networks.

Route Request (RREQ)

Source nodes send RREQ messages to reach other nodes. It contains start and end addresses, sequence numbers, and hops. Create reverse path entries and repeat the message across RREQ-receiving intermediate nodes until it reaches the destination or a valid route, the destination then send a RREP back.

Route Reply (RREP)

The final destination or path node may transmit RREP if it has a new route. Unicast returns via the RREQ's reverse route to the source. Intermediate nodes along this connection provide data transmission forward route entries [16].

Route Error (RERR)

RERR alerts the source when a connection breaks. It returns to the origin, which may start Route Discovery. In dense or mobile node networks, these control messages may increase overhead but are crucial for AODV. AODV's VANET performance relies on optimization.

- Control Messages in AODV Route Maintenance Procedure

Route Maintenance in the Ad-Hoc On-Demand Distance Vector (AODV) protocol keeps active routes on dynamic networks like VANETs legitimate. It can identify and react to link failures caused by node mobility or network disruptions via Route Error (RERR) signals [16,17].

If a connection is down, an intermediate node will issue an RERR message. This might happen when data packet transfers fail or nearby nodes time out. This notice lists broken links and their inaccessible destinations. RERR propagation alerts all active sources that rely on the invalidated route.

If the source node still needs to communicate with the destination after getting the RERR, it will erase the invalid route from its routing database and start a new Route Discovery operation. Through this process, AODV is able to swiftly adjust to changes in the network, ensuring that communication remains efficient and dependable.

Although RERR signals are essential for route maintenance, they may cause control overhead and delay to grow if they are generated often in unstable or highly mobile networks. If we want AODV to work better on VANETs, we need to optimize the Route Maintenance process, which means cutting down on needless RERR signals and adding predictive techniques [18].

4. RESEARCH METHODOLOGY

- Simulation Environment

The NS-2 (Network Simulator-2 / Ver. 2.35) simulator is used to run the VANET simulations in this work. The well-known Random Waypoint Mobility (RWM) model is followed by the nodes in the simulation region. A 2500 m × 1500 m rectangle serves as the virtual VANET zone for each scenario, which runs for 400 seconds. Every single simulation makes use of IEEE 802.11 MAC model (generic-layer) for the media access control (MAC) layer and IP for the network layer. A constant flow of data packets of 512 bytes is supplied by the Constant Bit Rate (CBR) traffic sources. See Table (1) for a complete rundown of all simulation metrics.

Table 1 Simulation parameters

Parameters	Values
Simulation Area	2500m X 1500m
Simulation Time	400 second
Network size	40,50 & 60 nodes
Vehicle Speed	From 40 to 100 km/h
Mobility Model	RWP Model
Traffic-Model	CBR Mode (four packets/s)
Routing Protocol	DSR / AODV
Pause Time / sec.	0,100,200 & 400
No. of sources	7,12,15 & 20
Channel Capacity	2 Mbps
Packet Size	512 Byte

- Performance metrics

During the simulation run for the DSR & AODV tests, a chosen performance metrics for the control messages of the standard protocols were examined. These metrics should be based on comparable VANET characteristics, such as the "size of the simulated region, bandwidth, traffic variety, energy resources", etc., and should be measured in relation to the number of nodes and pause time.

5. SIMULATION EXPERIEMENTS AND RESUTS

In practice, we test out a number of different simulation situations by dispersing VANET nodes throughout the whole simulation domain. In these cases, it includes:

- Modifying the no. of sources (Traffic-load)
- Modifying the pause-time of nodes (Speed)
- Modifying the no. of nodes (Network-size)

The modification sheds light on how control messages affect efficiency of the DSR and AODV routing protocols. Using the various simulation situations, we test these two on-demand routing protocols in a variety of environments. With regard to 3 parameters—namely, the no. of source nodes, the stop duration of mobile nodes, and the no. of VANET's nodes—the simulation research ran three separate scenarios, with each scenario simulating for 400 seconds.

In the first case study, the network size (number of VANET nodes) is modified between forty and sixty nodes. The second scenario in the experiment involves changing the number of source nodes (the provided load) from seven to twelve. In the third scenario of the simulation, the mobility halt duration of the nodes is adjusted from zero seconds to three hundred and thirty-five seconds.

In the coming sub-section, the scenarios and results are explained for simulations.

- Scenario 1: Effect of: Modifying the Number of Nodes

The amount of nodes, or the size of the VANET network, is altered in this simulated scenario. With any luck, this hypothetical situation will provide light on how the total amount of control messages varies with the number of nodes. When running the simulation, the real-world values for the number of mobile nodes in the VANET are40,50, and 60. When compared to the conventional parameters given in Table (1), the simulation parameters that differ are detailed in Table (2).

Table 2 The effected parameters of simulation scenario 1

“Parameter	Value
Number of nodes	40, 50, 60 nodes
Speed of nodes	40-100 km/h
Pause time	400 sec.
Number of sources	10 source nodes
Routing Protocol	DSR / AODV”

While three settings were run in simulation scenario 1, each with a different number of nodes, Table (3) shows an overall number of control-messages that were broadcast in successfully for the VANET network. So, we gathered the results of the simulation and put them in Figure (1) down below.

Table 3 No. of nodes Vs. Control Messages

“Control Messages vs. Varying Number of Nodes		Number of Nodes		
		40	50	60
NO. of Control Messages	DSR Control Messages	8612	19299	17651
	AODV Control Messages	25203	40248	203008”

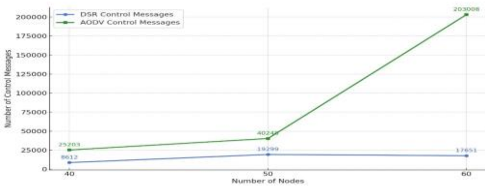

FIGURE 1 Control Packets vs. Nodes

The following graph compares the DSR and AODV protocols with respect to the quantity of control messages sent and received per node.

It shows that AODV produces many more control messages than DSR, particularly with an increase in the nomber of nodes.

Control overhead for each of the DSR and AODV protocols changes substantially with each increase in the number of nodes in a VANET, as seen in Fig.1 above. It seems that the control overhead of the AODV protocol is much larger than that of the DSR protocol, particularly as the number of nodes in MANT increases.

Using the information you provide, determine how the VANET's node count affects the DSR and AODV control packet counts. In the real world, the DSR protocol experiences a substantial increase (of 124%) in control packets from 8612: 19299 when the number of mobile nodes increases from 40: 50. As the nomber of nodes increases from 50 to 60, there is a modest drop in the nomber of control packets from 19299 to 17651 (of about 9%). While an increased expense of preserving routing information as the network expands may explain the first spike in control packets, the subsequent fall indicates that DSR either reaches a plateau or becomes more efficient.

On the other hand, when the number of mobile nodes increases, the AODV protocol shows a far more pronounced increase in the amount of control packets. The number of control packets increases dramatically from 25203 to 40248 while the number of mobile nodes rises from 40 to 50 (increase of about 60%). Nevertheless, the number of nodes might vary from 50 to 60 nodes, the number of control packets increases exponentially, reaching 203008 (increase of about 400%). This trend suggests that as the size of the network increases, AODV's control overhead is much greater than DSR's. This might be because the complexity of AODV's route discovery and maintenance procedures increases with the number of nodes.

In scenario 1, DSR reveals that the increase in the number of control packets in response to a rise in the number of mobile nodes is more manageable and predictable. It seems that DSR might provide better scalability for networks with additional nodes. On the other hand, AODV's control packet count skyrockets, which may mean more overhead and worse scalability in massive networks.

- Scenario 2: Effect of: Modifying the Number of Source-Nodes

In order to demonstrate how an amount of source nodes affects quantity of control messages in VANET, this simulated scenario modifies the number of source nodes (Offered Load). Five, eight, ten, and twelve mobile source nodes are the ones used in the simulations. In contrast to the typical parameters given in Table (1), the parameters used in the simulation experiment (1) are detailed in Table 4.

Table 4 Parameters effected simulation experiment 1

“Parameter	Value
Pause time	300s
Number of nodes	50 nodes
Speed of nodes	0-40-100 km/h
Number of sources	5, 8, 10 and 12 sources
Routing Protocol	DSR / AODV”

In this simulation, four different settings were run with different numbers of sources. Figure (2) shows the gathered simulation results, while Table (5) shows a total number of control messages successfully broadcast in the VANET communication net.

Table 5 Modifying source nodes vs. control messages

“Control Messages vs. Varying Number of Source Nodes		Number of Source Nodes			
		5	8	10	12
NO. of Control Messages	DSR Control Messages	16578	11502	28118	18106
	AODV Control Messages	93580	71725	50666	84359”

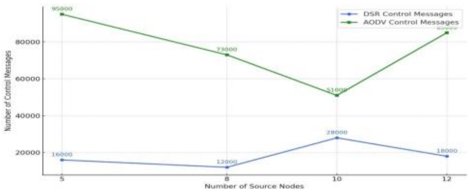

FIGURE 2 Control Packets vs. Sources

A graphical representation of the correlation between the DSR and AODV protocols' control message volumes and the number of source nodes.

DSR shows a non-linear trend, with the highest control messages at 10 sources.

AODV generally decreases with more sources but spikes again at 12 sources.

In scenario 2, the impact of the nomber of source nodes on the nomber of control packets for both DSR & AODV protocols that based on data were provided in above Table (5).

As the number of source nodes increased, DSR initially shower a rise in control messages followed by a slight decline, while AODV exhibits a steady increase.

In DSR protocol, the number of control packets starts at 16578 with 5 source nodes, dips to 11502 with 8 source nodes (decrease with about 30%), rises sharply to 28118 with (10) source nodes (increase by 144%), after then declines to 18106 with 12 source nodes (decrease with about 36%). One possible explanation for the discrepancy in the amount of control packets is that DSR's route management and discovery techniques function differently in networks of different sizes.

On the other hand, the number of control packets for the AODV protocol starts at 93580 with 5 sources, drops to 71725 with (8) source nodes (decrease with about 23%), drops even for further to 50666 with (10) source nodes (decrease with about 29%), and finally rises to 84359 with 12 source nodes (increase with about 66%). The decreasing trend between 5 and 10 source nodes implies that control messages become less necessary as the network expands, however the notable rise at 12 nodes shows possible congestion and more route requests in a more crowded type of network. It is possible that the difficulties in route discovery and maintenance across different network sizes are reflected in DSR's irregular pattern of control packet numbers, which in turn affects the scalability and efficiency of the system. At first glance, AODV seems to have a steadier decline in control packets, which might mean it's better suited for networks of smaller to medium-sized. However, the fact that it starts to rise at 12 nodes reveals that bigger networks can have spikes in congestion and control overhead. In networks where the number of nodes varies, network administrators may need to optimize protocol parameters or think about using a hybrid method in order to implement

DSR. Although AODV expands effectively at first, it requires careful management beyond a certain capacity to avoid congestion and unnecessary control messages as the network develops.

- Scenario 3: Effect of: Pause-time of Mobile Nodes

Simulation tries to illustrate the impact of mobile-node pause time on the amount of control messages in VANET by changing their pause time (speed). In practice, DSR and AODV each complete the simulation scenarios for 0, 100, 200, and 300 seconds independently. Parameters of first simulation experiment differ from the conventional values given in Table (1), as shown in Table (6).

Table 6 Parameters of simulation experiment 1

“Parameter	Value
Pause time	0, 100, 200 and 300 sec.
Number of nodes	50 nodes
Speed of nodes	0-40-100 km/h
Number of sources	10 sources
Routing Protocol	DSR / AODV”

Simulation scenario 3 has four environments with different sources. Figure (3) shows the simulation outcome, while Table (7) shows the total amount of broadcast for control messages in VANET network.

Table7 Modifying Pause-time of Nodes vs. Ctrl Messages

Control Messages vs. Varying Pause Time		Nodes Pause Time (sec.)			
		0	100	200	300
NO. of Control Messages	DSR Control Messages	25140	19894	14099	13247
	AODV Control Messages	50288	43104	35158	33261

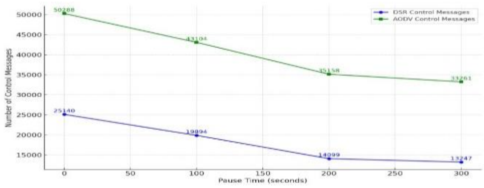

FIGURE 3 No. of Control Packets VS. Nodes Pause Time

Observations: Control messages tend to decrease with increasing pause duration in both DSR and AODV. Given that fewer topology changes result from longer stop intervals, which in turn reduce the requirement for control messages, this is not surprising. The larger number of control messages produced by AODV compared to DSR is indicative of a higher overhead. Based on the data supplied in Table 7, the second simulation scenario examines the effects of different node pause times on the control packets for both protocols in AODV and DSR.

The number of control packets for the DSR protocol starts at 25140 with a pause period of 0 seconds, drops to 19894 at 100 seconds (decrease of about 20%), drops even lower to 14099 at 200 seconds (decrease of about 29%), and hits rock bottom at 13247 at 300 seconds (decrease of about 6%). This steady drop indicates that less control messages are needed due to less route discovery and maintenance required by nodes with longer rest intervals, implying they are largely immobile for longer durations. The number of control packets for the AODV protocol starts at 50288 with a pause period of 0 seconds, drops to 43104 at 100 seconds (decrease of about 14%), drops even further to 35158 at 200 seconds (decrease of about 18%), and hits rock bottom at 33261 at 300 seconds (decrease of about 5%). Longer node pause durations improve AODV and DSR alike since they reduce the number of control packets sent and received due to route requests, error messages, and other related issues. A longer pause duration reduces the frequency of node movement, which in turn reduces the frequency of route breakages and a requirement for route discoveries, leading to a drop in the number of control packets for both protocols. At first, DSR reduces control packets more dramatically, but both protocols exhibit the same pattern of decreasing overhead as pause duration increases. A comparison of DSR and AODV reveals that the former is more efficient in less mobile, more stable networks due to the continuous drop in control packets as pause periods grow, while the latter also reaps the advantages of less mobile nodes due to the same trend. The effective management of control traffic with different stop lengths demonstrates AODV's responsiveness to changing network circumstances. Performance is enhanced by both DSR and AODV, and lessened the load on network resources, improved performance in situations involving more stable nodes (longer pause periods), and decreased control packet overhead as pause durations grow. In both DSR and AODV, the graph shows that control packets decrease with increasing pauze times; however, the total number of control packets is still more in AODV, higher than in DSR. This suggests that reduced mobility results in fewer control messages being generated...

Detailed Analysis Insights (Trend Explanation)

Scenario 2 (Varying Source Nodes):

The erratic expansion of DSR could be explained by the fact that the efficacy of route caching varies with the number of sources. Control messages in AODV tend to decrease with increasing source numbers, but they surge again around 12 sources. As a result of more complicated traffic, this can mean that route finding operations are more involved.

Scenario 3 (Varying Pause Time):

It is shown that more frequent route discoveries are triggered by increased mobility (lower pause durations) because both protocols demonstrate a decrease in control messages as pause time rises. In AODV, route maintenance is handled proactively by the continually higher control messages, whereas in DSR, route caching is used more to reduce overhead.

Performance Implications

Particularly in more dynamic networks, the increased control overhead of AODV may cause a rise in bandwidth usage. Although DSR's performance may be negatively affected in high-mobility settings by stale routes, its reduced control messages indicate improved scalability in packed areas.

Scalability Considerations

Even though it has more overhead, AODV may keep routes stable in networks with a lot of moving nodes and frequent modifications. While there fewer sources or when the environment is less dynamic, DSR may work better.

Below is a comparative table summarizing the data of all three scenarios

Table8 Comparative Overview – VANET Simulation Scenarios

Scenario	Metric	DSR	% Change	AODV	% Change	Key Observation
Node Count (40→50→60)	Control Packets	8,612 → 19,299 → 17,651	+124%, -8.6%	25,203 → 40,248 → 203,008	+59.7%, +404.3%	AODV overhead grows faster; DSR stabilizes after initial spike
Number of Sources (5→8→10→12)	Control Packets	16,578 → 11,502 → 28,118 → 18,106	-30.6%, +144.3%, -35.6%	93,580 → 71,725 → 50,666 → 84,359	-23.3%, -29.3%, +66.5%	DSR shows irregular pattern; AODV initially declines then rises at high source count
Pause Time (0→100→200→300 s)	Control Packets	25,140 → 19,894 → 14,099 → 13,247	-20.9%, -29.1%, -6.1%	50,288 → 43,104 → 35,158 → 33,261	-14.3%, -18.5%, -5.4%	Longer pause reduces mobility, lowering control overhead

Protocol Comparison and Implications

The data suggests that a DSR sends control signals more efficiently, especially in circumstances with many source nodes or clusters. DSR source routing requires the packet header to provide the whole route, which is the main reason. This reduces route updates and control message exchanges, which is useful in dense networks with multiple source nodes.

AODV's route discovery techniques and routing tables increase control message overhead as nodes and source nodes grow. In networks with high node density or many source nodes, AODV is less scalable than DSR due to frequent route-finding operations required to maintain connection. Overall, the findings provide meaningful insights into the scalability and efficiency of AODV and DSR protocols under varying VANET conditions. Furthermore, intelligent and adaptive routing strategies based in machine learning or artificial intelligence techniques could be explored to optimize control message overhead and enhance scalability in dense VANET environments. Real world testbed experiments may also be considered to validate the simulation results.

Intelligent algorithms or hybrid methods that combine DSR and AODV may improve control message overhead and routing efficiency in dynamic VANET systems.

6. CONCLUSIONS

On VANETs, control messages tested DSR and AODV, two prominent on-demand routing technologies. Comprehensive simulations examined how 40, 50, and 60 node networks influenced each protocol's control message output. DSR and AODV both vary in the control overhead and scalability.

DSR handled control messages more effectively than AODV created fewer control packets across network sizes. DSR's source routing and route caching simplify route finding and maintenance, boosting efficiency.

Network congestion or route caching may influence DSR's performance, as seen by the minor control message reduction at 60 nodes. More control messages are sent by AODV in bigger networks. The protocol's control cost was greater in dense VANETs due to route finding and maintenance, making scaling difficult. Optimizations eliminate un-necessary route-finding floods and increase AODV's performance in large-scale networks, as seen by the 60-node control message surge.

These discoveries are significant for VANET routing protocol implementation. The results indicate that DSR can exhibit lower control message overhead under specific network conditions, however, its performance may degrade in dense and large-scale VANET environment due to increased routing overhead and frequent topology changes. Conversely, adding adaptive control message methods or applying machine learning for route prediction may enhance AODV's scalability and performance.

Future work will extend the study by incorporating more realistic mobility models that reflect urban traffic patterns, road intersections, and vehicle density variations. Additional performance metrics such as packet delivery ratio, end-to-end delay, and throughput will also be analyzed to provide a more comprehensive evaluation.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest

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