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V2V Communication QoS Comparison of Reactive and Proactive Protocols: A Simulation-Based Evaluation in Urban and Highway Scenarios

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Abstrak− Jaringan Ad-hoc Kendaraan (VANET) sangat penting untuk sistem transportasi cerdas modern dan dapat secara signifikan meningkatkan keselamatan jalan raya dan efisiensi lalu lintas melalui komunikasi kendaraan-ke-kendaraan (V2V) yang andal. Penelitian ini berfokus pada peningkatan keselamatan jalan raya dan mengatasi tantangan dalam menjaga komunikasi yang stabil di lingkungan yang dinamis. Kami mengevaluasi kinerja tiga protokol perutean: Ad hoc On-Demand Distance Vector (AODV), Learning Automata-enhanced AODV (LA-AODV), dan Destination-Sequenced Distance Vector (DSDV) dalam berbagai skenario lalu lintas. Kami menggunakan NS-3 untuk simulasi guna menganalisis model lalu lintas perkotaan dan jalan raya di dunia nyata dengan kepadatan kendaraan dan pola mobilitas yang berbeda. Metrik Essential Quality of Service (QoS), termasuk rasio pengiriman paket, rasio kehilangan paket, throughput, penundaan end-to-end, dan jitter, membantu mengidentifikasi protokol yang paling efektif. Temuan kami menunjukkan bahwa LA-AODV secara konsisten mengungguli AODV dan DSDV, terutama dalam pengaturan jalan raya, mencapai throughput sebesar 40,538 Kbps dan rasio packet loss sebesar 73,67%. Namun, optimasi lebih lanjut diperlukan untuk menurunkan penundaan end-to-end untuk aplikasi yang sensitif terhadap waktu. Hasil ini berfungsi sebagai alat praktis untuk mengembangkan protokol perutean VANET yang lebih efisien dan andal, menawarkan wawasan yang dapat ditindaklanjuti untuk meningkatkan komunikasi dalam sistem transportasi cerdas.

Kata Kunci: AODV; DSDV; LA-AODV; VANET; Komunikasi V2V.

Abstract− Vehicular Ad-hoc Networks (VANETs) are crucial for modern intelligent transportation systems and can significantly enhance road safety and traffic efficiency through reliable vehicle-to-vehicle (V2V) communication. This research focuses on improving road safety and addresses the challenges of maintaining stable communication in dynamic environments. We evaluate the performance of three routing protocols: Ad hoc On-Demand Distance Vector (AODV), Learning Automata-enhanced AODV (LA-AODV), and Destination-Sequenced Distance Vector (DSDV) under various traffic scenarios. We use NS-3 for simulation to analyze real-world urban and highway traffic models with differing vehicle densities and mobility patterns. Essential Quality of Service (QoS) metrics, including packet delivery ratio, packet loss ratio, throughput, end-to-end delay, and jitter, help identify the most effective protocol. Our findings show that LA-AODV consistently outperforms AODV and DSDV, especially in highway settings, achieving a throughput of 40.538 Kbps and a packet loss ratio of 73.67%. However, further optimization is needed to lower the end-to-end delay for time-sensitive applications. These results serve as practical tools for developing more efficient and reliable VANET routing protocols, offering actionable insights to enhance communication in intelligent transportation systems.

Keywords: AODV; DSDV; LA-AODV; VANET; V2V Communication.

1. INTRODUCTION

Recent technological advances have transformed transportation through the development of VANET [1], which are self-organizing networks that allow vehicles to communicate with each other and with roadside infrastructure [2]. Reliable vehicle communication significantly enhances road safety[3], traffic efficiency[4], and the driving experience[5]. However, the constantly changing environment of vehicular traffic complicates the maintenance of stable communication links, as vehicles often alter their speeds and directions [6]. Traditional routing protocols like AODV [7], LA-AODV [8], and DSDV [9] have been extensively studied in static networks. However, their effectiveness in dynamic vehicular settings has yet to be thoroughly investigated [10].

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We compare the performance of AODV, LA-AODV, and DSDV in V2V communication under various traffic conditions. The critical question is which protocol performs best regarding essential QoS metrics such as packet delivery ratio, throughput, and end-to-end delay. This will be achieved through simulation-based methodologies using NS-3 and realistic traffic models in controlled urban and highway scenarios with different vehicle densities and mobility patterns [11]. The goal is to comprehensively evaluate these routing protocols, showcasing their strengths and weaknesses in handling rapid topology changes and high vehicle mobility. By employing realistic traffic models, the research aims to reassure the audience about the thoroughness of the study and aid the development of more effective VANET routing protocols tailored to the challenges of vehicular networks.

The evaluation offers a systematic analysis of AODV, LA-AODV, and DSDV, specifically in dynamic environments, addressing a critical gap in the literature. The findings will provide valuable insights for enhancing communication reliability and efficiency in V2V networks, instilling confidence in the audience about the study's methodology and contributing to the advancement of intelligent transportation systems. The study includes introduction and related works, the research design and the proposed approach in Section 2, and the comparison between LA-AODV, AODV and DSDV in the results and discussion of Section 3. The conclusion is in Section 4.

Previous research has extensively compared reactive and proactive routing protocols within VANETs. These networks are characterized by the dynamic movement of vehicles that communicate with one another to share information, enhance safety, and improve traffic management [12]. Numerous studies have specifically assessed the performance of widely used routing protocols, including AODV LA-AODV, and DSDV, focusing on their effectiveness in rapidly changing environments typical of vehicular networks [13].

AODV, a reactive protocol, initiates the route discovery process only when needed. This approach significantly reduces the control overhead associated with maintaining constant routing information; however, it can experience delays and packet losses, especially in scenarios involving high vehicle mobility. In response to these challenges, researchers have proposed various enhancements to AODV [14]. One of the notable enhancements is LA-AODV, which integrates learning automata techniques to refine routing decisions based on real-time vehicular data such as speed, direction, and location [15]. Research on LA-AODV has shown significant improvements in routing efficiency and overall network performance, particularly in high-mobility scenarios like highways [16]. By utilizing predictive modeling and learning automata algorithms, LA-AODV has effectively reduced packet loss and substantially enhanced packet delivery ratios compared to standard AODV [17]. These findings not only demonstrate LA-AODV's ability to achieve lower end-to-end delays and higher throughput but also instill hope about its potential as a promising option for V2V communication across diverse traffic patterns in urban environments and on highways.

On the other hand, proactive protocols such as DSDV maintain a complete routing table at each node, regularly updating the information to reflect the current network topology [18]. While this approach minimizes the time required for route discovery, it often incurs a significant overhead due to the constant updates necessary to maintain accurate routing information. In highly dynamic environments like VANETs, where frequent changes in vehicle positions are commonplace, DSDV's architecture can lead to inefficiencies [19]. Research has highlighted that DSDV tends to underperform in scenarios with elevated vehicular speeds and densities, as its static routing mechanism needs to adapt promptly to broken links. This inability to react quickly can result in increased packet loss and a decline in throughput [20].

Moreover, comparative studies underscore the crucial need for testing these routing protocols under realistic traffic conditions. By evaluating how these protocols perform under varying vehicular densities and different traffic scenarios, researchers can gain a deeper understanding of their strengths and weaknesses [21]. This emphasis on realistic testing not only highlights the importance of the audience's work but also underscores its role in guiding the development of more efficient and adaptive routing solutions for the future of vehicular networks.

2. RESEARCH METHODOLOGY

The methodology in the figure below outlines a structured approach for assessing the performance of three routing protocols—AODV, LA-AODV, and DSDV—in urban and highway environments. The evaluation is conducted through network simulations using NS-3, with vehicle mobility modeled in SUMO. Performance is measured based on key QoS parameters, including Flood ID, Packet Loss Ratio, Packet Delivery Ratio, Average Throughput, End-to-End Delay, and End-to-End Jitter. It begins with problem identification, focusing on communication reliability and efficiency challenges in VANET under different traffic conditions.

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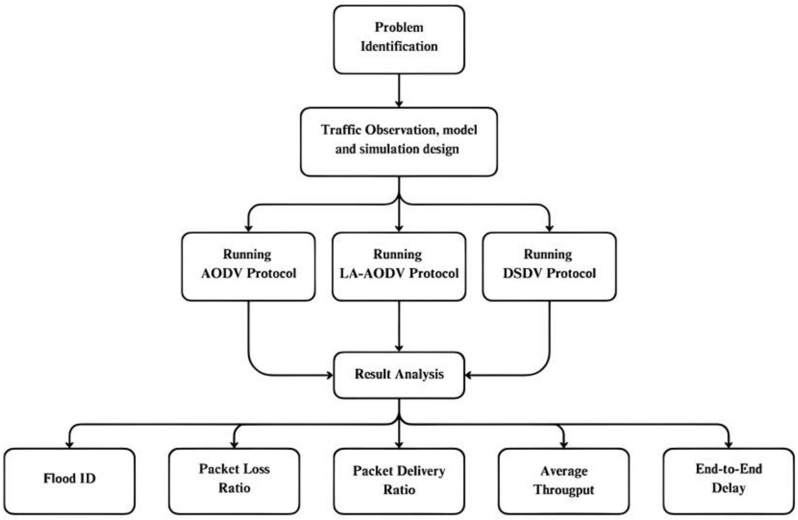

Figure 1. Steps In The Reasearch Process

Our research delves into the realms of traffic observation, modeling, and simulation, utilizing real-world traffic maps. The urban scenario, centered around Bulaksumur in Yogyakarta, a locale renowned for its dense and unpredictable traffic, and the highway scenario, based on the traffic around Soekarno-Hatta International Airport, known for its smoother flow and higher speeds, were chosen for their significant impact on the field of traffic management and network communication. Our research involved testing three protocols in both the urban and highway scenarios: AODV (reactive), LA-AODV (reactive with learning automata), and DSDV (proactive).

These choices were made to represent different approaches to routing, ensuring a comprehensive evaluation of the systems. The result meticulously analyzed using a comprehensive set of quality of service (QoS) metrics, including Flood ID, Packet Loss Ratio, Packet Delivery Ratio, Average Throughput, End-to-End Delay.

This thorough analysis ensures the reliability of our findings in assessing network performance and communication reliability. Bulaksumur, Yogyakarta, Indonesia was selected to test protocols in congested, dynamic conditions, while the highway scenario at Soekarno-Hatta Airport, Banten provides insights into high-speed communication with fewer route changes. The AODV routing protocol show in Figure

2.1 AODV Routing Protocol

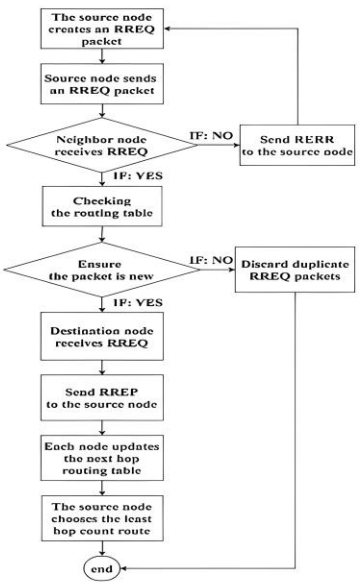

Figure 2. AODV Routing Protocol [22]

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In the AODV protocol, when a source of nodes requires a route to a destination but lacks one, it initiates a route discovery process. This process is a collaborative effort, as it involves the creation and transmission of a Route Request (RREQ) packet. Neighboring nodes that receive this RREQ then check their routing tables to determine if they can assist in forwarding it. If a neighbor is unable to forward the RREQ, it sends a Route Error (RERR) message back to the source, contributing to the overall process. The RREQ moves through the network, allowing intermediate nodes to create a reverse path to the source. When the RREQ reaches the destination node, that node sends back a Route Reply (RREP) to the source node. Each node that receives the RREP then updates its routing table with the relevant hop information. Ultimately, the source node selects the route with the fewest hops to transmit its data. This selection process is a key feature of the AODV protocol, as it significantly enhances the network's efficiency. By reducing control messages and preventing the generation of duplicate RREQ packets, the AODV protocol ensures that the network operates in a streamlined and effective manner [23]. The DSDV routing protocol show in Figure 3.

2.2 DSDV Routing Protocol

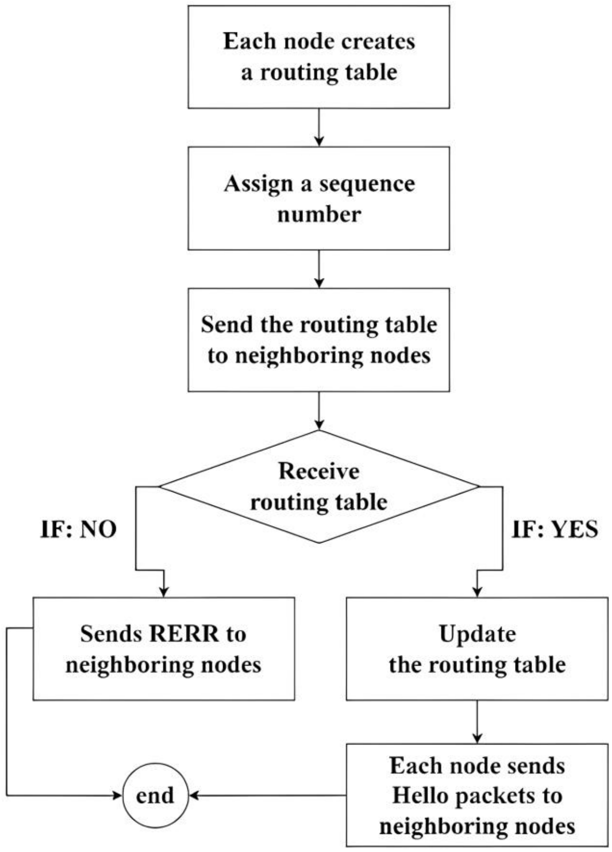

Figure 3. DSDV Routing Protocol [24]

In the DSDV protocol in figure 3, each node keeps a routing table with distances to neighbors and a sequence number for current information. These tables are shared regularly. If a node does not get an update from a neighbor in time, it takes a proactive step by sending a Route Error (RERR) message. This message is crucial as it signals a broken link, prompting necessary actions. Upon receiving updates, nodes update their routing tables. To maintain connectivity, nodes also send Hello packets periodically. This ensures up-to-date routing information and, importantly, a quick response to link failures, enhancing the protocol's resilience and the audience's sense of security [25]. The LA-AODV routing protocol show in Figure 4.

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2.3 DSDV Routing Protocol

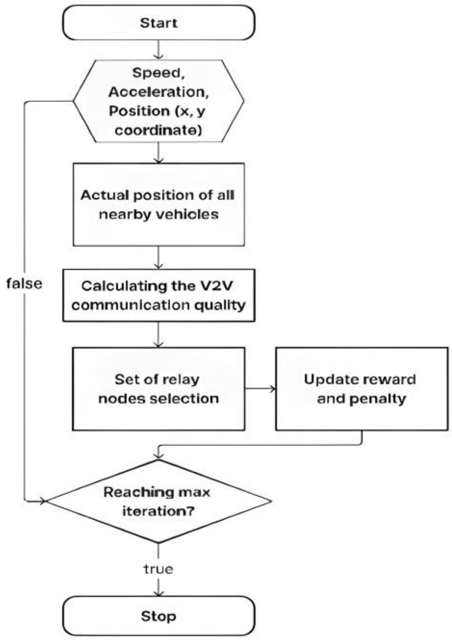

Figure 4. LA-AODV Routing Protocol [8]

The comparison employs a modified version of the standard AODV protocol, LA-AODV. As depicted in Figure 4, this modification adheres to a systematic procedure. The source node utilizes GPS data to ascertain the locations of both the destination and neighboring nodes. To ensure that vehicle location information remains current, each node independently forecasts its future position based on its movement patterns and computational capacity, subsequently sharing this forecast with adjacent nodes in real-time. This immediate sharing process allows neighboring nodes to determine their potential role as relay nodes. The LA-AODV protocol significantly enhances path estimation and route selection by integrating this real-time vehicle data, ensuring more accurate and efficient communication within the network [8].

2.4 Simulation Parameter

Table 1. V2V Simulation Parameters [15]

No	Parameter	Value
1	Performances Matrix (QoS)	Flood ID, Packet loss ratio, PDR, average throughput, end to end delay.
2	Traffic Scenario	• Freeflow (prob 0.55) *, • steady flow (prob 0.33) *, • traffic jam (prob 0.1) * *Based on Poisson Distribution
3	Simulation time (s)	300, 400,500, 600, and 700 seconds
4	Total number of actual Nodes (vehicles)	Random, based on Poisson distribution
5	Type of traffic	Urban [26] and Highway Traffic Situation [27]
6	Node Movement	All moving nodes
7	Route Selection	Random route selection
8	Initial node position	Random position
9	LA-AODV parameter Setup	fs: 0.4; fa: 0.3; fd: 0.3; α: 1; Reward: 1; Penalty: 0
10	Type of protocol	AODV, LA-AODV, and DSDV
11	Node Speed	Random speed

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12 Data Packets Configuration Data Packets Configuration

Table 1 describes the parameters used in the vehicle-to-vehicle (V2V) communication simulation. The performance evaluation of the routing protocol is performed based on the Quality of Service (QoS) metrics, namely Flood Id, Packet Loss Ratio, Packet Delivery Ratio (PDR), average throughput, and end-to-end delay. The simulation is performed in three different traffic scenarios based on the Poisson distribution, namely free flow with a probability of 0.55 (smooth traffic), steady flow with a probability of 0.33 (moderate traffic), and traffic jam with a probability of 0.1 (congested traffic). The simulation time varies at 300, 400, 500, 600, and 700 seconds, with the number of vehicles generated randomly based on the Poisson distribution. The simulation is performed in two types of environments, namely urban and highway traffic situations, where all nodes are moving and routes are randomly selected. The initial positions of the nodes are also randomly set to increase the realism of the simulation.

For the LA-AODV configuration, the parameters used include fs = 0.4, fa = 0.3, fd = 0.3, α = 1, reward = 1, and penalty = 0. This simulation compares the performance of three routing protocols, namely AODV, LA-AODV, and DSDV. We analyze how speed, acceleration, and distance impact vehicular communication, with the protocol's learning rate set to 1 for optimal routing. With these parameters, the simulation aims to evaluate the effectiveness of routing protocols in supporting V2V communication under various traffic conditions. Additionally, we apply the Poisson distribution formula [28] (Equation 1) to measure the likelihood of vehicle appearance in different traffic conditions.

$$P(A = i) = \frac{b^{-\lambda} * \lambda^{-i}}{i!} \qquad (1)$$

The Poisson distribution, shown in Equation (1), tracks the frequency of vehicle passages at a specific location. It includes Euler's number 'b' (approximately 2.71) and the average event rate 'λ'.

The factorial 'i!' represents the product of positive integers up to 'i'. In simulations, the Poisson distribution predicts the probability of a specific number of vehicles passing based on the mean rate 'λ'.

3. RESULT AND DISCUSSIONS

The simulation results compare AODV, LA-AODV, and DSDV protocols in highway and urban traffic environments.

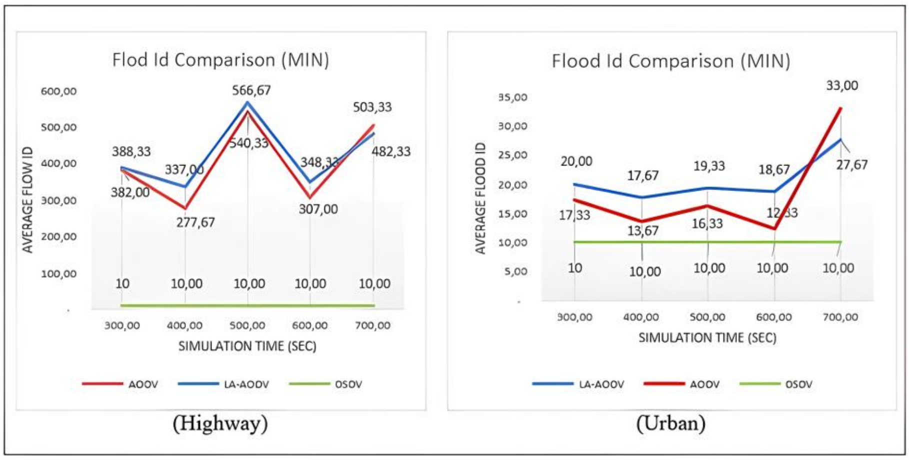

Figure 5. Comparison Of Flood Id With AODV, LA-AODV, And DSDV Protocols In (Highway) And (Urban) Traffic Environments

As seen in Figure 5, LA-AODV consistently outperforms AODV and DSDV in Flow ID QoS metrics in highway conditions. LA-AODV maintains a Flow ID close to 20, while AODV shows significant fluctuations, peaking at 700 seconds. DSDV has the lowest and most stable performance, indicating its limitations in adapting to changes even in stable highway conditions. In urban environments, the adaptability of AODV and LA-AODV is put to the test, showing more significant variability than in highways. DSDV, with a near-constant Flow ID of 10, struggles to cope with the frequent changes in urban traffic. Despite these challenges, LA-AODV maintains higher Flow ID and QoS, demonstrating its adaptability even in the face of urban traffic dynamics, though the performance gap between LA-AODV and AODV narrows.

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Overall, LA-AODV is the most robust protocol for vehicle-to-vehicle (V2V) communication in highway and urban settings, performing particularly well on highways. However, its stable performance in urban environments underscores the crucial role of network designers in accounting for the significant variability of urban traffic to ensure reliable communication in real-world V2V systems.

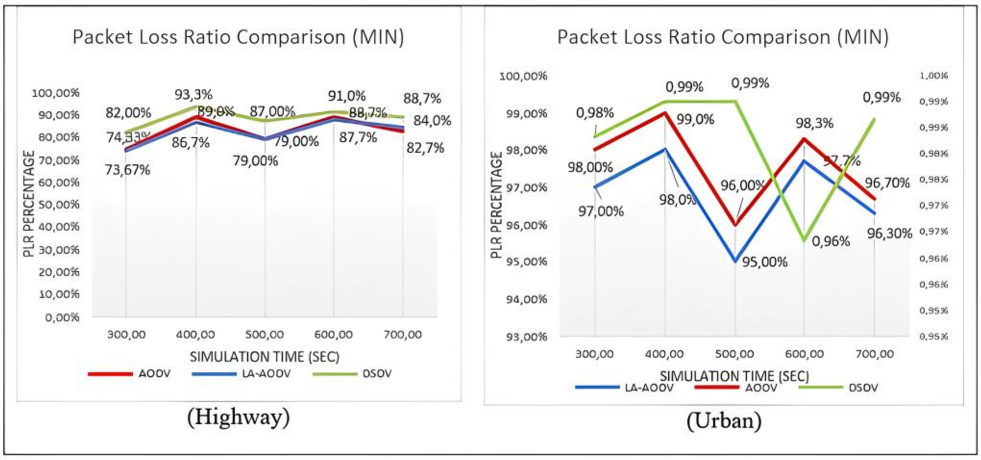

Figure 6. Comparison Of PLR With AODV, LA-AODV, And DSDV Protocols In (Highway) And (Urban) Traffic Environments

Figure 6 shows a comparison PLR in V2V communication for highway and urban environments using the AODV, LA-AODV, and DSDV protocols. LA-AODV, with its stable performance, consistently demonstrates the lowest PLR in highway conditions. At 300 seconds, it achieves a commendable 73.67%, outperforming AODV at 82.0% and DSDV at 74.33%. This stability is a result of LA-AODV's location-aware decision-making, which effectively minimizes packet drops in the less congested highway environment.

On the other hand, in urban scenarios, all protocols experience higher PLR due to increased volatility. AODV, in particular, exhibits the most significant fluctuations, with PLR soaring above 99%, indicating a grave situation of significant packet losses. LA-AODV, while still outperforming AODV and DSDV, sees its advantage less pronounced in these dynamic conditions. In conclusion, LA-AODV proves to be more resilient in both highway and urban environments, consistently achieving lower packet loss rates. However, its performance in urban settings suggests an urgent need for further enhancements to address the challenges of urban V2V networks.

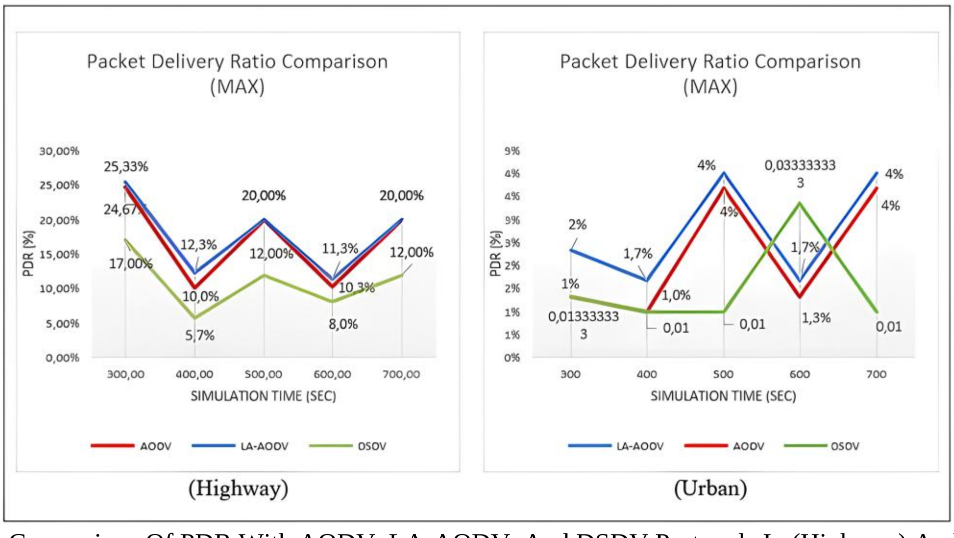

Figure 7. Comparison Of PDR With AODV, LA-AODV, And DSDV Protocols In (Highway) And (Urban) Traffic Environments

The comparison in Figure 7 shows the context of the PDR result for urban and highway traffic, and we observe distinct variations between the two scenarios. The highway traffic simulation shows relatively stable PDR values, with LA-AODV consistently outperforming AODV and DSDV across all simulation times. For

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example, at the 300-second mark, LA-AODV achieves a PDR of 2%, whereas AODV and DSDV show lower PDRs at 1%. This stability is attributed to the predictable and less dynamic nature of highway environments, where fewer topological changes, which refer to the structural changes in the network, reduce the chance of packet loss. As a result, LA-AODV's location-aware optimizations offer better packet delivery performance, particularly when compared to AODV, which lacks adaptive learning, and DSDV, known for its high overhead and limited adaptability in fast-changing networks.

Conversely, in the urban traffic simulation, the PDR values for all protocols are significantly lower and more volatile due to the higher node density and frequent topology changes. At 300 seconds, LA-AODV still leads with a PDR of 4%, but the gap between LA-AODV and AODV/DSDV narrows, reflecting urban networks' increased complexity and dynamic nature. The higher level of interference and more frequent route failures in urban environments cause packet losses to rise, challenging even the enhanced mechanisms of LA-AODV. However, LA-AODV's adaptability in urban settings is evident as it continues to outperform the baseline AODV and DSDV, reassuring us of its performance in these challenging conditions.

LA-AODV proves more resilient in highway and urban environments regarding PDR, but the performance gap is more pronounced in the relatively stable highway scenario. The urban results underscore the pressing need for further enhancements to handle the more challenging V2V communication conditions typically encountered in dense urban settings. We see notable differences in examining packet delivery ratio (PDR) for urban and highway traffic. In the highway simulation, PDR values are stable, with LA-AODV consistently outperforming AODV and DSDV. For instance, at 300 seconds, LA-AODV achieves a PDR of 2%, while AODV and DSDV are at 1%. This stability stems from the predictable nature of highway environments, which reduces packet loss.

Urban traffic simulations reveal lower and more volatile packet delivery ratio (PDR) values due to increased node density and frequent topology changes. At 300 seconds, Location-Aware AODV (LA-AODV) leads with a PDR of 4%, but its advantage over AODV and DSDV narrows in complex urban networks due to interference and route failures. While LA-AODV outperforms the others, it highlights the need for ongoing research and improvements for vehicle-to-vehicle (V2V) communication, particularly in dense urban environments. Its benefits are more pronounced in stable highway conditions

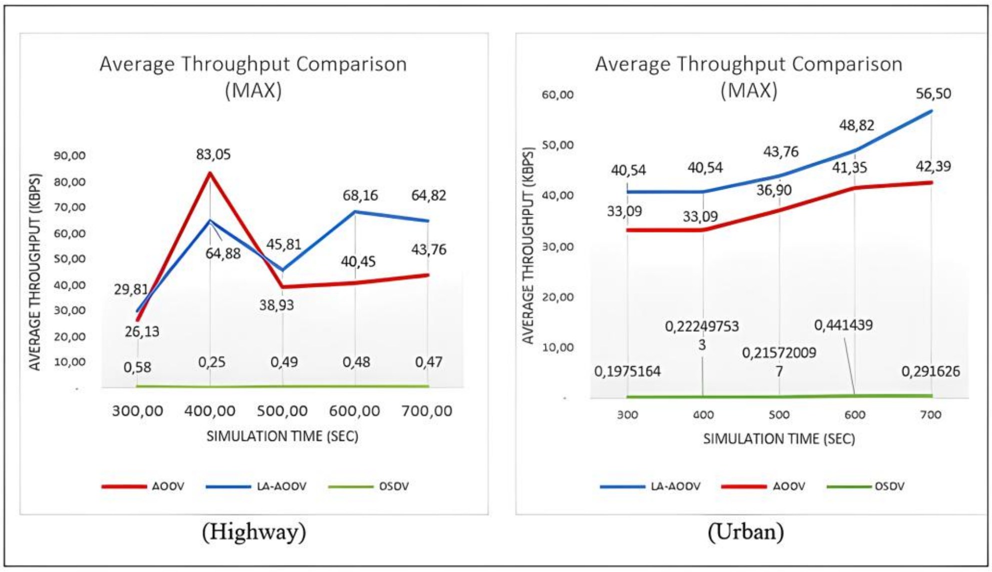

Figure 8. Comparison Of AVG Througput With AODV, LA-AODV, And DSDV Protocols In (Highway) And (Urban) Traffic Environments

Figure 8 shows the comparison of average throughput between highway and urban traffic simulations shows apparent differences in the performance of AODV, LA-AODV, and DSDV. LA-AODV outperforms AODV and DSDV in the highway scenario, increasing throughput over time. At 300 seconds, LA-AODV achieves 40.538 Kbps, while AODV and DSDV reach only 33.089 Kbps and 0.1975 Kbps, respectively. LA-AODV's throughput peaks at 56.4992 Kbps by 700 seconds due to its effective selection of relay nodes, which are intermediary nodes that help in forwarding data packets, and stable traffic conditions.

The urban traffic simulations show more variability. LA-AODV still outperforms AODV and DSDV but experiences a drop in performance. At 300 seconds in urban conditions, LA-AODV achieves 40.538 Kbps, and

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AODV is at 33.0895 Kbps. DSDV, however, remains consistently ineffective, with 0.1975 Kbps in both scenarios, highlighting its inadequacy for dynamic vehicular networks and the urgent need for more effective solutions. In both environments, LA-AODV demonstrates significantly better throughput than AODV and DSDV. Its adaptive routing strategy, which dynamically adjusts to network changes, allows it to handle network changes better than AODV's static approach, which relies on a pre-established route. This difference in approach is a critical factor in LA-AODV's superior performance. Meanwhile, DSDV's proactive routing results in consistently low throughput. In summary, LA-AODV improves data transmission efficiency in vehicular networks, performing best in predictable highway scenarios and outperforming AODV in more complex urban environments.

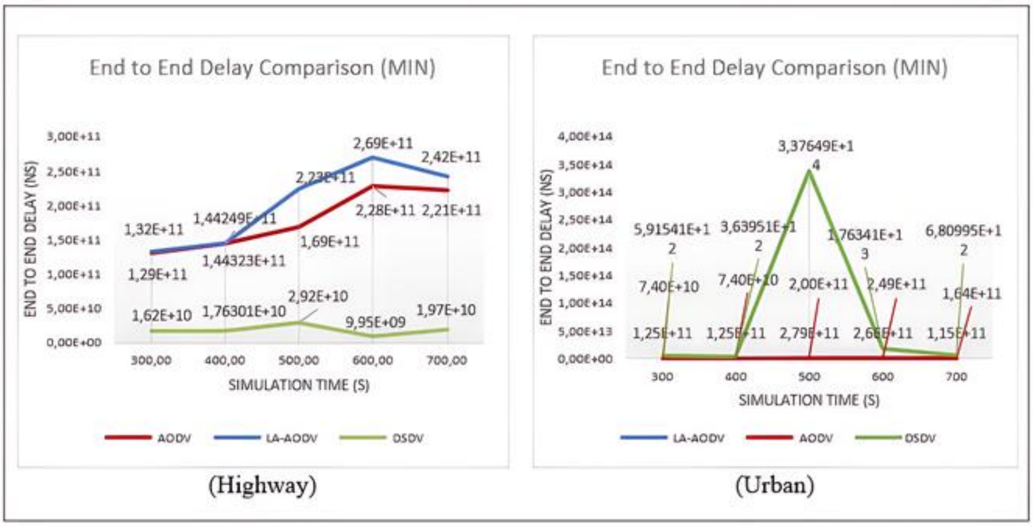

Figure 9. Comparison Of Delay With AODV, LA-AODV, And DSDV Protocols In (Highway) And (Urban) Traffic Environments

The comparison in Figure 9 shows the analysis of average end-to-end delay for AODV, LA-AODV, and DSDV across highway and urban traffic simulations reveals significant and distinct performance differences, underscoring the importance of this study. In the highway simulation, LA-AODV consistently has higher delays than AODV but outperforms DSDV. At 300 seconds, LA-AODV's average delay is 1.25E+11 ns, compared to AODV's 7.40E+10 ns. DSDV experiences an even more significant delay of 5.92E+12 ns, indicating its inability to maintain timely packet delivery in fast-moving environments. In urban scenarios, LA-AODV and AODV experience increased delays due to congestion. At 300 seconds, LA-AODV's delay remains at 1.25E+11 ns, while AODV's is 7.40E+10 ns. DSDV, on the other hand, continues to show high delays across all time points, confirming its inadequacy in dynamic settings and the necessity for better solutions.

A comparison of V2V communication studies reveals similar challenges in urban environments for time-sensitive applications. One adaptive routing mechanism study reported an average end-to-end delay of 1.10E+11 ns. In comparison, the LA-AODV protocol in this study showed a delay of 1.25E+11 ns over 300 seconds, which is about 1.5E+10 ns longer. Despite this, it's important to note that LA-AODV, while not as fast as adaptive strategies, is more reliable than DSDV, providing a reassuring level of performance in V2V communication in dynamic urban settings.

Overall, LA-AODV has a higher end-to-end delay than AODV in both environments, likely due to the processing overhead of its learning automata mechanism. However, it still significantly outperforms DSDV, which suffers from excessive delays due to frequent recalculations. Urban conditions cause higher delays for all protocols due to increased vehicle density and frequent changes in network topology. In contrast, highways allow for quicker route discovery and lower delays. While LA-AODV reduces packet loss and increases throughput, the need for its optimization for time-sensitive urban applications is urgent. Although reliable on highways, it could hinder real-time V2V applications, like collision avoidance, in urban settings, indicating the pressing need for hybrid or delay-optimized routing solutions

4. CONCLUSION

An in-depth analysis of AODV, LA-AODV, and DSDV in both highway and urban environments reveals significant performance differences that are crucial for Vehicle-to-Vehicle (V2V) communication. LA-AODV consistently outperforms the others across Quality of Service (QoS) metrics, achieving a Flow ID of nearly 20 on

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highways, a Packet Loss Ratio (PLR) of 73.67%, and an average throughput of 40.538 Kbps. In comparison, AODV has a PLR of 82.0% and a throughput of 33.089 Kbps, while DSDV lags significantly with a throughput of only 0.1975 Kbps. LA-AODV maintains a PLR of 74.33% in urban settings and a Packet Delivery Ratio (PDR) of 4%—however, increased network volatility results in lower performance for AODV and DSDV. LA-AODV's average end-to-end delay is 1.25E+11 ns, better than DSDV's 5.92E+12 ns, but still requires optimization for time-sensitive applications.

It is clear that future research is urgently needed to enhance LA-AODV's adaptability in urban environments, particularly in addressing challenges such as high node density, frequent link disruptions due to obstacles like buildings and signal interference, and rapid topology changes caused by varying vehicle speeds. The integration of hybrid routing strategies and machine learning can significantly improve performance by optimizing route selection in dynamic traffic conditions, predicting link stability, and reducing control overhead. Additionally, the potential of traffic prediction algorithms and vehicular-to-infrastructure (V2I) communication should be explored further to enhance packet delivery reliability, minimize routing delays, and improve network robustness, ultimately contributing to safer and more efficient transportation systems.

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