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Performance Assessment of Optimized Link State Routing Protocol on Vehicular Ad Hoc Network Simulation

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Abstract

Vehicular Ad-hoc Networks (VANETs) are dedicated forms of wireless communication networks designed to handle the challenges of vehicular environments, including high mobility, varying traffic densities, and constantly changing topologies. These factors necessitate the development and evaluation of routing protocols to ensure reliable data communication between vehicles. This study evaluates the performance of the Optimized Link State Routing (OLSR) protocol within Vehicular Ad-hoc Networks (VANETs), focusing on its capability to handle different traffic densities and dynamic environments. Reliable data communication in VANETs is critical due to the high mobility and constantly changing topologies, especially in urban and highway settings. Using NS-3 for network simulation and Simulation of Urban MObility (SUMO) for realistic vehicular mobility modelling, we conducted a series of simulations to assess OLSR's performance in low-density and high-density scenarios across highway and urban environments. Key performance metrics, including packet delivery ratio (PDR), end-to-end delay (E2ED) and throughput were analyzed to capture OLSR's strengths and weaknesses in each setting. The analysis showed that OLSR excels in low-density highway scenarios, achieving a PDR of 100% and low E2ED. However, in high-density urban settings, the protocol encounters performance challenges, with a reduced PDR of 81.40% and a high E2ED of 85.52 seconds, indicating delays in data transmission. These findings emphasize the limitations of OLSR in dense urban environments, highlighting the necessity for adaptive routing protocols that can improve performance in complex, high-density vehicular networks.

Keywords: OLSR; VANET; QoS; Highway; Urban; NS-3; SUMO.

1. Introduction

Vehicular Ad-hoc Networks (VANETs) are a specialized subset of wireless networks focusing on communication between moving vehicles [1, 2]. VANETs are designed to improve traffic efficiency, enhance road safety, and extend infotainment and transportation services [3]. While VANETs share some similarities with Mobile Ad-hoc Networks (MANETs), they must operate under more critical conditions, including fast-moving vehicles and rapidly changing topologies [4]. VANETs differ significantly from MANETs due to these unique challenges, such as maintaining low delay and jitter under high mobility [5, 6]. Two primary communication infrastructures for VANETs are Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I), both of which facilitate real-time data exchange to improve road

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safety and navigation efficiency [7, 8]. To ensure stable communication in VANETs, the choice of routing protocol is crucial. According to [9], high mobility in vehicular environments frequently changes network structures, making routing a major challenge. According to Quy et al. [10], the decision-making process for routing protocols has been a long-standing area of research. Therefore, for VANETs to provide high-quality services, appropriate routing protocols must be developed and evaluated.

Optimized Link State Routing (OLSR) is a proactive, topology-based routing protocol widely used in both MANETs and VANETs. It employs the Multi-Point Relay (MPR) technique to optimize traffic by selecting specific nodes to forward data, minimizing network overhead [11]. As highlighted by Gupta [12], OLSR's design allows it to adapt well to the dynamic conditions of VANETs, providing manageable transmission delays and lower average latency. On the contrary, according to Abdeen et al. [13] and Kaur et al. [14], as the number of hosts increases, the OLSR protocol control message overhead also increases, which can affect overall network performance. Therefore, it is critical to evaluate OLSR's ability to handle different traffic densities in VANET environments. In addition to routing protocol performance, Quality of Service (QoS) plays a pivotal role in determining the network's capacity to deliver optimal service levels [15]. QoS in VANETs is vital for applications requiring timely and reliable communication, such as emergency notifications [16]. Common performance metrics used to evaluate QoS in VANET simulations include throughput, packet delivery ratio (PDR), end-to-end delay (E2ED), and packet loss [17]. These metrics provide a comprehensive evaluation of how well the network supports communication under different traffic and mobility conditions.

Recent research has highlighted various enhancements and limitations of OLSR in different scenarios. Pratama et al. [18] conducted a comparative analysis of four ad hoc routing protocols used in VANETs with the UDP protocol for packet delivery. The study simulated the protocols under three propagation loss models using a map of Jakarta, utilizing NS3, SUMO, and OpenStreetMap for the simulation. The configuration involved 30 nodes over 150 seconds, with vehicle speeds set at 30 m/s, 50 m/s, and 100 m/s. The results showed that variations in the propagation model did not significantly affect throughput or goodput. However, the Friis Propagation Loss Model revealed that the OLSR protocol performed outstandingly, whereas other protocols performed relatively poorly. The limitation identified by the authors was the need for further development in routing protocols capable of adapting to dynamic VANET environments without compromising communication reliability and efficiency.

Deshpande et al. [19] compared OLSR with AODV, DSR, and GRP in a VANET environment using the OPNET modeler 14.5. The focus was on throughput and latency characteristics. The configuration used 40 nodes in a 10 km by 10 km square area with a seed value of 128 and voice application enabled. Performance metrics included throughput, network load, media access delay, traffic drop, and delay. OLSR exhibited a throughput of 18 bits/second and a network load of 2200 bits/second, with increasing delays and traffic drops as the number of mobile hosts grew. The study highlighted that OLSR required significant CPU power and bandwidth to handle control messages and compute optimal paths, especially as the network size increased. A limitation of the study was the high computational demand for OLSR as node density increased, which could affect its scalability.

Shobana & Raj [20] proposed an enhancement to QoS and route selection in VANETs by integrating an Intelligent Swarm-based Firefly Algorithm (ISFF) into AODV and compared it to OLSR-PSO. The aim was to improve QoS and find optimal routes in VANETs. The simulation was run in NS2 with 10 to 100 nodes across a 2050 x 2050 m area, with a fixed data rate of four packets per second in a random mobility model. The results showed that the FFA model outperformed the PSO model in terms of Packet Delivery Ratio (PDR) and End-to-End Delay (E2ED), demonstrating its superior performance. A limitation of this approach was its dependency on optimal parameters for the swarm-based algorithm, which may require fine-tuning for different network conditions.

Elaryh Makki Dafalla et al. [21] focused on optimizing the route for Voice over IP (VoIP) traffic to improve QoS. They used OLSR to evaluate VoIP services in real-time. Simulation tools included Linux OS, OLSR Switch Agent, Wireshark, MATLAB, and Ekiga. Four scenarios were tested, starting with a single hop and increasing the hops progressively. The results indicated that after implementing OLSR, the average network delay decreased by 18.72%, from 121.67 milliseconds to 102.48 milliseconds, and the mean jitter rate decreased by 20.42%. The study also noted that packet loss was reduced by 128.6%. A limitation was that the study only evaluated a limited set of scenarios and did not explore the impact of various network conditions on VoIP QoS.

Alrfaaei & Akki [22] investigated contention levels in OLSR for assessing the quality of VANET connectivity. The study aimed to identify the vehicle coverage range or traffic density that correlates with good or poor contention levels. Using Matlab Mobility Simulation, they simulated up to 500 nodes with a maximum speed of 100 km/h and a minimum speed of 50 km/h over a 4-lane road. The results showed that OLSR experienced high contention when the vehicle density was low (12 vehicles/km), and low contention at high density (160 vehicles/km). The study also showed that OLSR performed poorly with low vehicle coverage and medium to high traffic density, due to excessive retransmissions and high burst errors. A limitation was the simulation's focus on fewer than 500 nodes, which may not fully represent large-scale VANETs.

Laanaoui & Raghay [23] proposed an Advanced Greedy Forwarding Mechanism to enhance OLSR in VANETs by reducing convergence time and ensuring low E2ED and latency during neighbor discovery. The study used NS3 and SUMO to simulate traffic in Marrakech, Morocco, with 200 to 500 nodes and vehicle speeds between 20 km/h to 60 km/h. The simulation lasted 200 seconds, and the results showed that the Greedy-OLSR (G-OLSR) approach provided the best PDR and E2ED performance. With increased traffic, the PDR of G-OLSR improved, and the E2ED decreased. A limitation was the study's restricted focus on a single city and traffic model, which may not generalize to other urban settings.

Hota et al. [24] compared proactive and reactive routing protocols in VANET deployment, evaluating OLSR, AODV, and DSDV using four propagation models (FRIIS, Two Ray Ground, Log-Distance, Nakagami). The study used NS3, SUMO, and OpenStreetMap for realistic simulations in Rourkela. Results showed that OLSR outperformed AODV and DSDV in throughput, packet delivery ratio (PDR), and end-to-end latency in both static and real-world scenarios, especially with 71 cars connected for Basic Safety Message (BSM) transmission. The limitation of this study was the reliance on relatively simple models, which might not capture the full complexity of VANET environments.

Tareef et al. [25] presented a comparative analysis of routing protocols by applying machine learning algorithms to classify performance data from OLSR and other protocols in various VANET scenarios. The study simulated different scenarios by adjusting simulation duration, node count, and node velocity to model different vehicle movement conditions. The results showed that OLSR achieved an average throughput of 2.735 kbps and a PDR of 94%. As vehicle speed increased, the PDR slightly decreased to 92%. The study highlighted OLSR's strength in PDR, although other protocols showed better performance in terms of throughput and E2ED. A limitation of this study was the limited simulation environment, which might not capture the full range of dynamic scenarios in real-world VANET applications.

Kachooei et al. [26] proposed a rateless coding-based geocast routing method for OLSR, aimed at forwarding data to a destination region more efficiently. The study modified OLSR to support geocasting, reducing signaling latency. Using NS2 and SUMO, simulations were run with 45 to 180 nodes in a 1 km x 1.4 km map for 1000 seconds, with vehicle speeds ranging from 5 m/s to 30 m/s. The results showed that Tuned-OLSR outperformed AODV-based and CALAR-DD protocols, particularly in high-density networks, by improving PDR and reducing latency. A limitation was the potential trade-off in overhead and control packet complexity for high-density scenarios.

Ahmed et al. [27] explored on enhancing the MPR selection in VANETs using a proposed algorithm called Wingsuit Flying Search. The primary focus is on mitigating broadcast storms, a significant challenge in VANETs. The Wingsuit Search-Optimized Link State Routing Protocol (WS-OLSR) optimizes routing by reducing the number of broadcasted control and topology messages, ensuring that data transfers occur through a minimal number of nodes and paths. The simulations were conducted using NS3 on an Ubuntu 18.04 platform, with a node range of 25 to 200 and a fixed vehicle speed of 20 m/s in a simulation area of 1000m x 1000m. Comparison was made between WS-OLSR and traditional OLSR, focusing on metrics like the number of MPRs, throughput, and topology control (TC) packets. Results show that WS-OLSR maintains a more stable throughput even with a higher number of nodes (150-200), and significantly reduces TC packets, especially in denser node environments. WS-OLSR also reduces the number of MPRs needed to cover 95% of the mobile nodes, outperforming traditional OLSR in these areas. However, a limitation of the algorithm is its reduced effectiveness when the total number of nodes is below a certain threshold.

Yang et al. [28] focused on improving the OLSR protocol using a mechanism called Multi-objective Particle Swarm Optimization (MOPSO). The proposed method aims to optimize OLSR parameters such as *HELLO_INTERVAL* and *TC_INTERVAL* to balance cost and delivery performance in VANETs. Simulations were conducted using NS2 and SUMO across two scenarios: common VANET conditions using random waypoint and data flow models, and realistic scenarios based on a map of Málaga from OpenStreetMap. The configuration included random node movements in a square with varied velocities for the general case. Results show that in realistic VANET scenarios, traditional OLSR achieved better packet loss ratio (PLR) at 9.3% compared to 10.7% for MOPSO-OLSR. However, MOPSO-OLSR excelled with an average E2ED of 14.7 ms compared to 22.7 ms for OLSR. While traditional OLSR outperformed MOPSO-OLSR in throughput (5488.4 kbps vs. 5404.6 kbps), the normalized routing load (NRL) of MOPSO-OLSR was superior (10.10% vs. 19.50%). Nevertheless, the key limitation is the slight trade-off in throughput and PLR for the proposed mechanism, but it demonstrates significant advantages in E2ED and NRL.

Suvarna & Bappalige [29] focused on comparing four MANET routing protocols in a VANET scenario to analyze their performance in exchanging safety messages. The study emphasizes that an effective routing protocol is critical for enabling VANET applications like safety, collision detection, and data transfer latency analysis. The simulation employs OpenStreetMap, SUMO, and NS3 tools to model traffic on a real-world scenario: the Cross Street Road intersection at NH 66 and Solapur Mangalore Highway, known for extreme congestion during rush hours. The configuration includes different vehicle types, with simulations running for 100 seconds. Results show that OLSR has a relatively low receive rate compared to alternative protocols but exhibits zero MAC overhead. Additionally, OLSR ranks second in average goodput, falling between AODV and DSDV. However, a key limitation is its relatively lower receive rate, which may impact its effectiveness in safety-critical applications.

Borah & Ganga [30] focused on evaluating the influence of propagation models (FSPL, ITU-R P.1411, Nakagami) on the performance of VANETs using the OLSR protocol. The study employs a mechanism that investigates the adaptability of these models to improve routing efficiency in urban settings with varying vehicle densities. The simulation utilizes SUMO to generate realistic mobility scenarios and NS3 to evaluate network performance. The configuration includes vehicle densities of 30, 60, 90, and 120, with parameters such as IEEE 802.11p, 20 dBm transmission power, and 200-byte packet sizes. The results reveal that the FSPL model performs best in terms of PDR, ITU-R P.1411 excels in minimizing E2ED, and Nakagami underperforms due to its handling of obstacles. However, a major limitation of this work is its inability to account for dynamic urban factors such as weather and changing infrastructure.

Marinov [31] focused on a comparative analysis of two routing protocols, AODV and MTP, in urban VANET environments. The mechanism centers on MTP's introduction of Link Time (LT), which improves message stability by addressing issues caused by node movement. Simulations were conducted using NS2 with a configuration involving 50 vehicles traveling at 50 km/h within a 1000x1000 m area. The study applies the Two-Ray Ground propagation model and IEEE 802.11p for communication. Results show that MTP outperforms AODV in throughput (78 Kbps vs. 72 Kbps) and E2ED (0.013 seconds vs. 1.017 seconds), demonstrating its superior stability and efficiency. However, the limitation of this work lies in its focus on a single scenario with only 50 vehicles, and it does not consider more complex traffic conditions or emerging technologies.

Varsha & Jhariya [32] focused on the characterization of AODV, OLSR, and ZRP routing protocols in a real-world VANET scenario. The study examines performance metrics such as throughput, delay, and jitter to determine protocol efficiency under varying vehicular densities. The mechanism involves using NETSIM interfaced with SUMO, with simulations conducted in Delhi's Kamla Nagar area. The configuration includes 20, 40, and 80 vehicles operating with IEEE 802.11p and the Rayleigh fading model. The results show that AODV achieves the highest throughput, ZRP the lowest jitter and delay, and OLSR performs intermediately across all metrics. However, one key limitation is the narrow focus on specific performance metrics, which excludes broader analyses of urban mobility impacts.

Despite these findings, OLSR has not been extensively evaluated under different traffic conditions and realistic urban settings. Thus, this study aims to bridge the gap by evaluating OLSR's performance in two distinct VANET scenarios: highway and urban environments using map data from Melaka, Malaysia. This study will assess the protocol's performance under both dense and sparse traffic conditions, focusing on key Quality of Service (QoS) metrics such as PDR, end-to-end delay (E2ED), and throughput. This evaluation aims to provide insights into the protocol's feasibility for VANETs, especially under different traffic densities and topological challenges.

2. Simulation Approach

2.1. Architecture

The simulation approach involves a coordinated process using multiple tools to generate and analyze vehicular network scenarios. OpenStreetMap (OSM) is utilized to create and export map data, which is then imported into the Simulation of Urban MObility (SUMO) tool to develop vehicular traffic scenarios. For the simulations, specific parameters such as vehicle types, arrival rates, and traffic light configurations were carefully configured in SUMO to reflect realistic urban conditions. For example, the vehicle types were defined to include standard cars, each with varying acceleration and deceleration profiles, while arrival rates were set to simulate both peak and off-peak traffic hours.

SUMO produces a trace file that is subsequently imported into NS-3, where it interfaces with the OLSR module and Wi-Fi libraries for the simulation. In NS-3, simulation parameters such as the number of nodes, transmission ranges, and packet sizes were adjusted based on the scenario type (urban vs. highway). For instance, transmission ranges of 50 m, 250 m, and 500 m were tested to evaluate their impact on packet delivery ratio (PDR) and end-to-end delay (E2ED) in both scenarios. The results are gathered and saved in CSV format for subsequent graph generation and Quality of Service (QoS) analysis. To ensure efficiency in the results, multiple iterations of each scenario were conducted, varying the vehicle density, transmission range, and mobility patterns to capture a wide range of network behaviors. The entire simulation process is conducted on a virtual machine running Ubuntu 22.04.4 LTS, as shown in Figure 1, which illustrates the simulation block diagram.

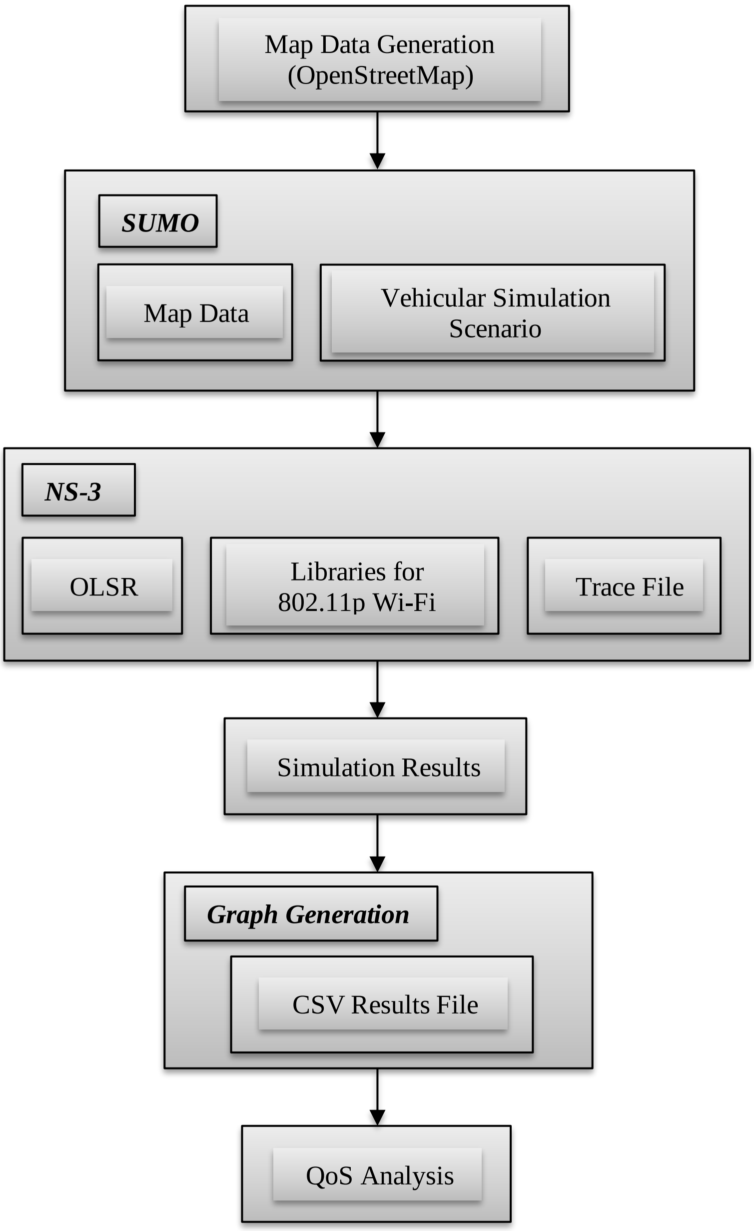

Figure 1. Simulation Block Diagram

2.2. Scenario

There are two different scenarios developed to evaluate OLSR performance under different conditions. These conditions cover Malacca City Centre (urban) and three lanes in each direction (highway), each 1 km in length. Traffic density was controlled by defining node densities and vehicle flow rates for low and high-density conditions to simulate realistic urban and highway traffic patterns. For the Malacca City Centre scenario, SUMO generated traffic flows with node densities of 40 vehicles (low density) and 120 vehicles (high density) over a simulation period of 90 seconds to capture movement patterns across a large area. Vehicle speeds were set within the typical range of 10-30 km/h to reflect urban traffic behavior, accounting for stops, acceleration, and deceleration due to intersections and traffic signals. Transmission ranges of 50 m, 250 m, and 500 m were tested to analyze variations in packet delivery ratio (PDR). Detailed parameters for this scenario are listed in Table 1. Figure 2 shows the OSMWebWizard initial settings for Malacca City Centre, Malaysia, while Figure 3 shows the settings in Google Maps. Figure 4 illustrates the SUMO GUI for the urban scenario.

Table 1. Simulation Parameter of Malacca City Centre Scenario

Parameter	Settings
Tools Used	NS-3.29
Routing Protocol	OLSR
Wireless Mode	802.11p
Number of Nodes	40, 120
Propagation Model	Two Ray Ground Propagation Loss Model
Transmission Ranges	50 m, 250 m, 500 m
Number of Sinks	10
Nodes' Maximum Speed	10-30 km/h
Simulation Time	90s

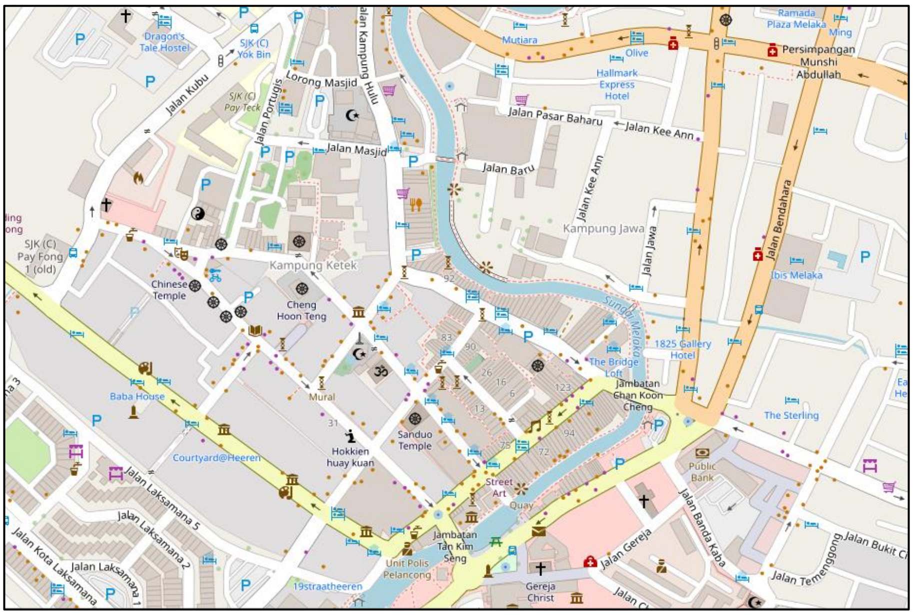

Figure 2. Malacca City Centre, Malaysia on OSMWebWizard

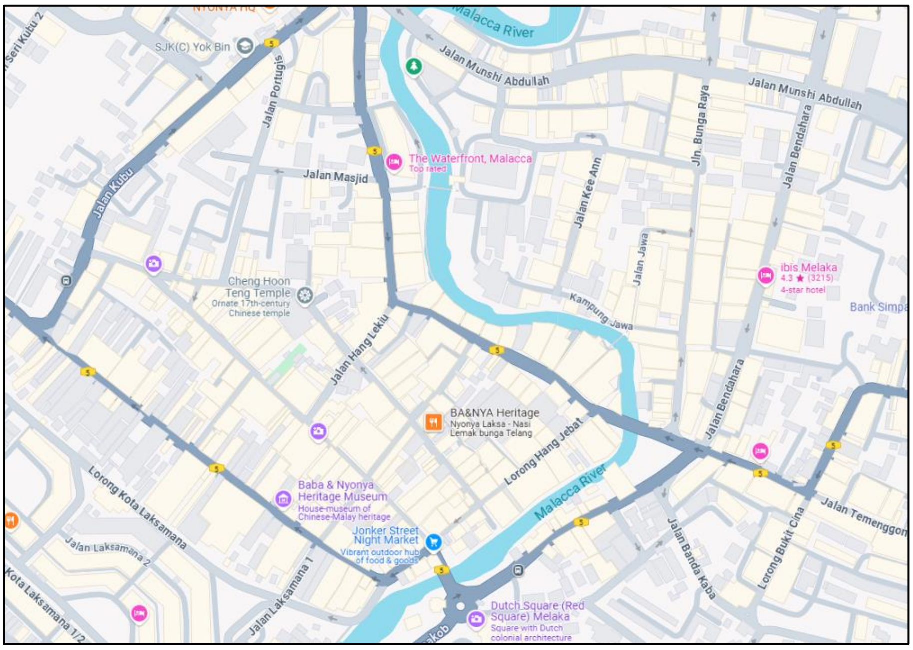

Figure 3. Malacca City Centre, Malaysia on Google Maps

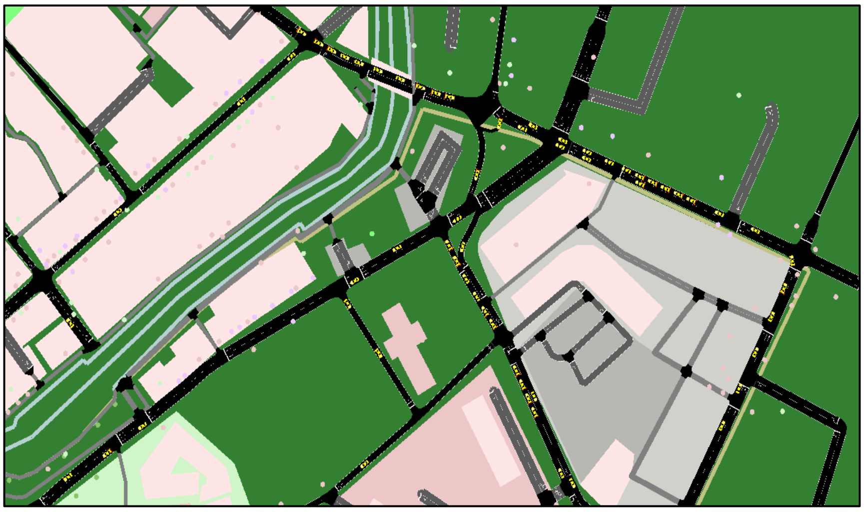

Figure 4. Malacca City Centre, Malaysia Traffic Simulation on SUMO GUI

In the highway scenario, SUMO modeled a 1 km-long highway with either 20 nodes (low-density) or 50 nodes (high-density) to represent different traffic volumes. Vehicles in this scenario moved at speeds between 60-100 km/h, reflecting typical highway conditions. For low-density simulations, 50 seconds of simulation time was sufficient for observing stable vehicle movement, while the high-density simulation allowed for contrasting performance observations. This setup also incorporated variability in vehicle speed to simulate overtaking and lane-switching behaviors. The parameters for this highway scenario are detailed in Table 2. Figures 5 and 6 illustrate the SUMO GUI for the highway scenarios.

Table 2. Simulation Parameter of Highway Scenario

Parameter	Settings
Tools Used	NS-3.29
Routing Protocol	OLSR
Wireless Mode	802.11p
Number of Nodes	20, 50
Propagation Model	Two Ray Ground Propagation Loss Model
Transmission Ranges	50 m, 250 m, 500 m
Number of Sinks	10
Nodes' Maximum Speed	60-100 km/h
Simulation Time	50s

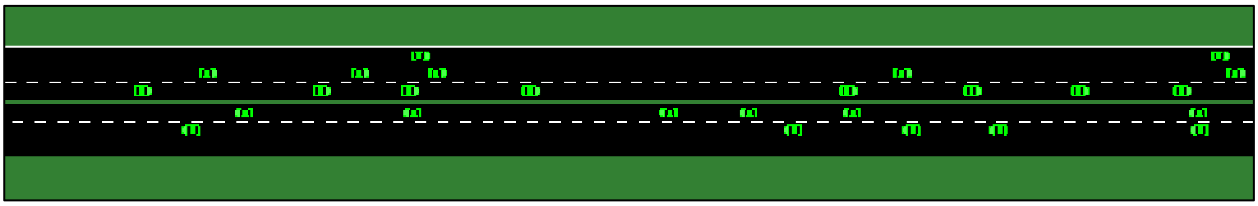

Figure 5. SUMO Simulation of Highway Scenario – High Density

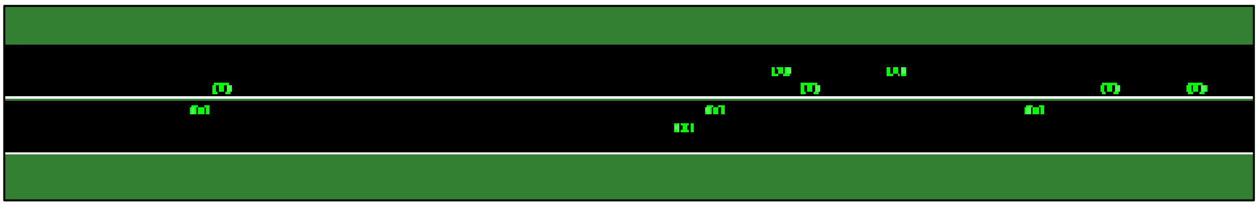

Figure 6. SUMO Simulation of Highway Scenario – Low Density

3. Result and Discussion

To evaluate the performance of the Optimized Link State Routing (OLSR) protocol in different scenarios, two modules were utilized: the Wave module and the FlowMonitor module. The Wave module primarily provides packet delivery ratio (PDR), while the FlowMonitor module offers additional metrics including end-to-end delay (E2ED) and throughput.

3.1. Wave Module

The Wave module in NS-3 is designed specifically for vehicular networks, focusing on the IEEE 802.11p standard for vehicular communications. This module is used to simulate and analyze the performance of basic safety messages (BSMs) exchanged between vehicles. The Wave module uses the 'WaveBSMHelper' class, which specifically collects statistics related to the transmission of BSMs. The 'WaveBsmStats' object within this class tracks attributes such as packet size, transmission interval, and communication ranges. Three transmission ranges were set as attributes of 'WaveBsmStats': 50 meters (short distance), 250 meters (medium distance), and 500 meters (long distance). The 'WaveBsmStats' object outputs the results every second throughout the simulation time, with average results displayed at the end. This data is used to compute the Packet Delivery Ratio (PDR), which reflects the effectiveness of the safety message delivery process. PDR is calculated by dividing the number of expected received packets by the actual received packets and multiplying by 100.

In the Malacca City Centre (urban) scenario with a low-density setting of 40 nodes, PDR values were 94.71% at short distance, 79.71% at medium distance, and 41.72% at long distance. These results indicate that as transmission distance increases, PDR decreases due to higher packet loss over greater distances. In the high-density setting with 120 nodes, the PDR dropped further to 83.22% at short distance, 55.53% at medium distance, and 26.03% at long distance. The larger number of nodes in a confined urban area leads to increased congestion and interference, which reduces the overall reliability of message delivery, especially at extended ranges (see Figure 7).

In the highway scenario, the low-density setup with 20 nodes achieved a high PDR of 96.16% at short distance, 93.84% at medium distance, and 83.92% at long distance. This high PDR even at extended distances suggests that highways provide a more favorable environment for vehicular communications due to reduced obstacles and lower interference compared to urban areas. In the high-density highway scenario with 50 nodes, the PDR was 89.99% at short distance, 78.05% at medium distance, and 55.30% at long distance. Although the PDR is lower than in the low-density highway setup, it is still higher than in the urban scenario, reinforcing the notion that highways allow for reliable communication due to lower node density and direct line-of-sight conditions (see Figure 7).

The results show that PDR decreases with increasing node density. This is particularly noticeable in urban environments, where high-density scenarios (120 nodes) suffer from packet loss, particularly at medium and long distances. The urban environment develops issues like signal interference and multipath propagation, which further impact the reliability of communication. As transmission range increases from 50 meters to 500 meters, PDR decreases across all scenarios due to signal attenuation and increased likelihood of interference. However, the decline is gradual in highway scenarios compared to urban scenarios, highlighting the challenging nature of urban communication environments for VANETs.

The highway scenario consistently performs better than the urban scenario in terms of PDR, especially in low-density conditions. This suggests that highways are suited for reliable VANET communication, while urban environments require further optimization, such as adaptive routing mechanisms, to improve performance under varying density conditions. These findings highlight the importance of scenario-specific configurations and the need for adaptive solutions to enhance PDR, particularly in complex urban settings with high node density.

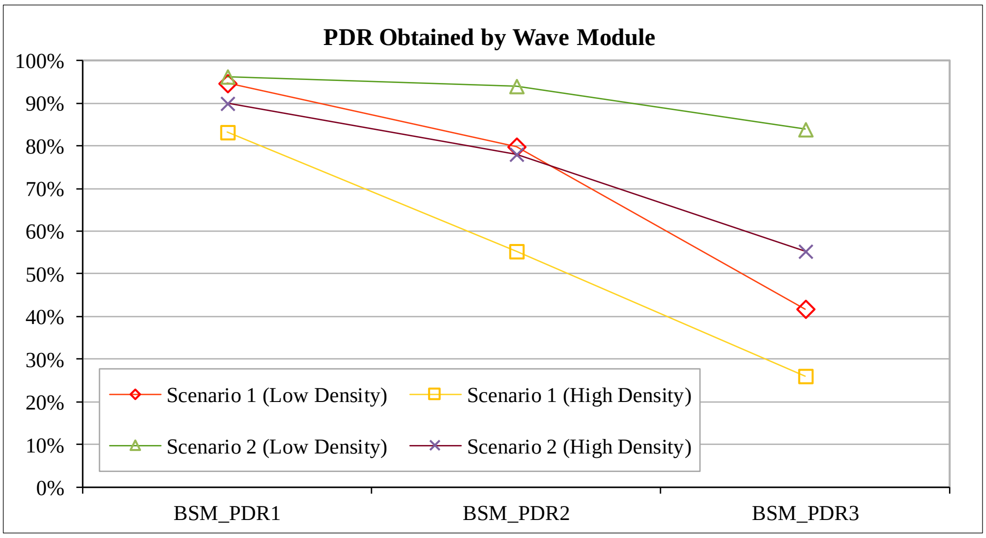

Figure 7. PDR Results Obtained by Wave Module

3.2. FlowMonitor Module

The FlowMonitor module in NS-3 is designed for monitoring and analyzing network traffic. It is used to gather a wide range of performance metrics, including packet delivery ratio (PDR), end-to-end delay (E2ED), and throughput. FlowMonitor achieves this by installing probes on network nodes to track packet flows and collect detailed statistics.

For the Malacca City Centre scenario, the low-density scenario achieved a PDR of 84.69%, indicating relatively high reliability, even with fewer vehicles present, possibly due to reduced interference and congestion. However, the high-density scenario recorded a slightly lower PDR of 81.40%. This decline suggests that as vehicle density increases, the likelihood of packet loss slightly rises, possibly due to increased signal interference or collisions among packets. In contrast, the Highway scenarios, both the low-density and high-density highway scenarios, achieved a perfect 100% PDR. This result suggests that the highway setting, regardless of density, provides an environment where packets are consistently delivered. This reliability may be due to the linear topology of the highway, which often results in fewer obstacles and a more stable signal path compared to urban environments (see Figure 8).

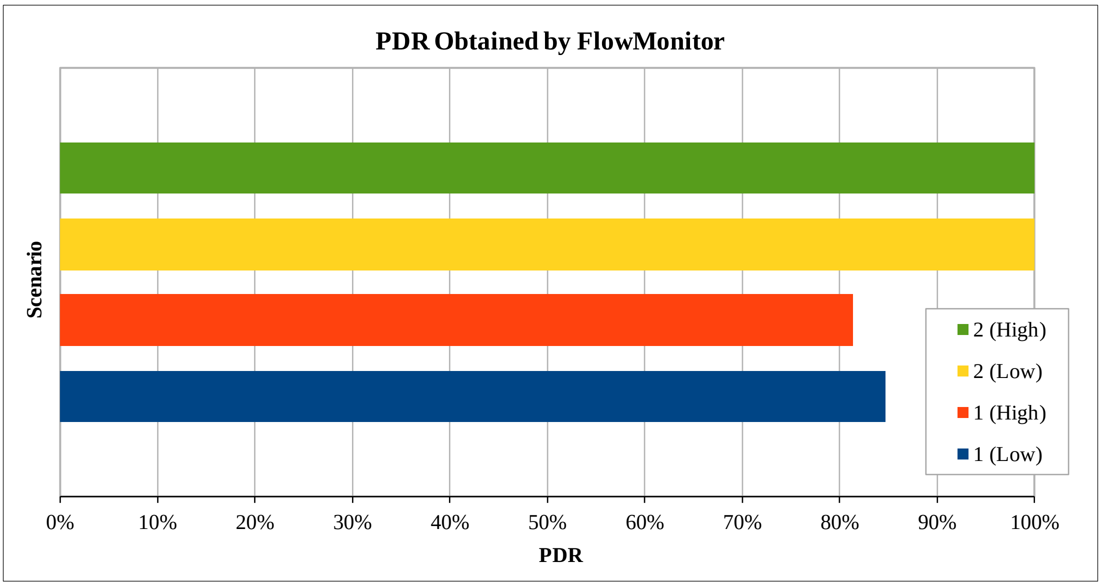

Figure 8. PDR Obtained by FlowMonitor

For the Malacca City Centre scenario, the low-density setup had an E2ED of 36.986 seconds, while the high-density setup showed a much higher delay of 85.521 seconds. The increase in delays at high density could be attributed to congestion, as more vehicles may cause data to queue longer before reaching its destination, especially in an environment with buildings and other obstacles. In contrast, the Highway scenarios, the delay was minimal, with the low-density and high-density setups recording E2EDs of 0.621 seconds and 0.837 seconds, respectively. This low delay in highway environments indicates faster communication, likely due to fewer obstacles and a clearer signal path, allowing packets to travel fast even when vehicle density is higher (see Figure 9).

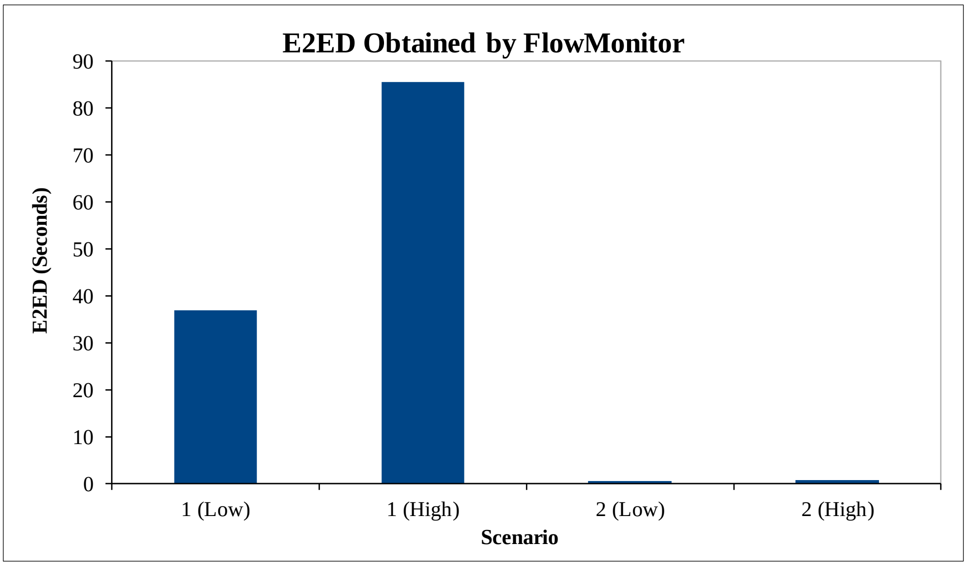

Figure 9. E2ED Obtained by FlowMonitor

For the Malacca City Centre scenario, the low-density scenario achieved a throughput of 2.438 Kbps, while the high-density scenario recorded a slightly lower throughput of 2.316 Kbps. This reduction at higher density levels might be attributed to packet collisions and interference, reducing the data transmission rate. On the other hand, the Highway scenarios, both low-density and high-density setups, reached a throughput of approximately 2.890 Kbps. The highway's consistent throughput, even with higher densities, aligns with the higher PDR observed, indicating that highways provide a more stable environment for continuous data flow (see Figure 9).

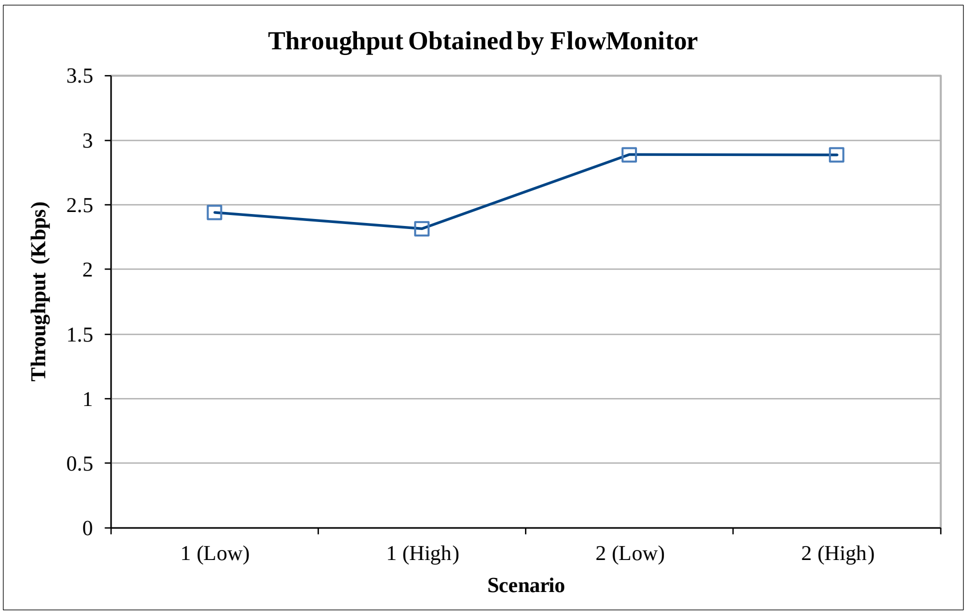

Figure 10. Throughput Obtained by FlowMonitor

3.3. Comparison of Wave and FlowMonitor Module

The comparison between the Wave and FlowMonitor modules reveals differences in their performance metrics, particularly in PDR. Despite both modules being capable of measuring PDR, they employ different methodologies, resulting in differing outcomes. The Wave module relies on the WaveBsmHelper and WaveBsmStats classes to gather statistics on BSM transmission between nodes. It calculates PDR by assessing the number of transmitted versus received BSMs. The primary focus of the Wave module is on PDR, and it provides statistics on BSM exchanges at different communication ranges (short, medium, and long). However, this approach may lead to lower PDR values because it only evaluates a specific type of traffic and does not capture all network activities. On the other hand, the FlowMonitor module proposes a comprehensive analysis by installing probes in network nodes to monitor packet flows throughout the simulation. This allows FlowMonitor to collect detailed statistics on different performance metrics, including PDR, E2ED, and throughput. The broader monitoring scope of FlowMonitor results in higher PDR values, as it captures more detailed network performance data.

When comparing PDR results, it is useful to consider the average PDR values for the Wave module, as it provides results for different communication ranges. For instance, in the analysis, the PDR values from the Wave module are consistently lower than those obtained by FlowMonitor. This difference is particularly significant in Scenario 2, where the difference in PDR is 26.57%. This variation highlights the impact of the different measurement approaches: while the Wave module’s PDR values are lower due to its focus on BSM, FlowMonitor’s wider scope provides a comprehensive view of network performance. Table 3 indicates the PDR comparison between the Wave and FlowMonitor modules.

Table 3. PDR Comparison of Wave and FlowMonitor Module

Metric	Scenario	Wave Module	FlowMonitor Module
PDR	Malacca City Centre (Low Density)	94.71% (Short), 79.71% (Medium), 41.72% (Long)	84.69%
	Malacca City Centre (High Density)	83.22% (Short), 55.53% (Medium), 26.03% (Long)	81.40%
	Highway (Low Density)	96.16% (Short), 93.84% (Medium), 83.92% (Long)	100%
	Highway (High Density)	89.99% (Short), 78.05% (Medium), 55.30% (Long)	100%

3.4. Comparison Between Scenarios

The analysis of performance metrics across high-density and low-density scenarios in Malacca City Centre and a highway reveals distinguished differences. These variations in performance metrics, such as PDR, E2ED, and throughput, are influenced by the density of nodes and the characteristics of each scenario. The PDR is significantly higher in low-density scenarios compared to high-density ones, regardless of the location. In both Malacca City Centre and the highway, low-density scenarios consistently demonstrate better PDR. This improvement is likely due to reduced routing overhead and fewer collisions in low-density scenarios, leading to more successful packet transmissions. High-density environments, with their increased node count, face routing challenges and congestion, resulting in lower PDR.

The E2ED also demonstrates better performance in low-density scenarios. The reduced number of nodes in low-density settings minimizes channel contention, which leads to faster packet delivery and lower delays. In high-density scenarios, the higher node density contributes to increased contention for channel access, which in turn results in higher E2ED. Therefore, lower node density correlates with reduced delay and improved network performance. Throughput follows a similar trend, with low-density scenarios achieving higher throughput compared to high-density scenarios. This is attributed to fewer collisions and less contention in low-density environments, which allows for efficient use of network resources. However, the difference in throughput between high-density and low-density scenarios on highways is minimal, with only a slight variation of 0.00004 Kbps. This suggests that while low-density scenarios are favorable for throughput, the highway's stable and consistent route characteristics contribute to relatively similar throughput results across different densities. Figure 11 shows the overall results for all scenarios.

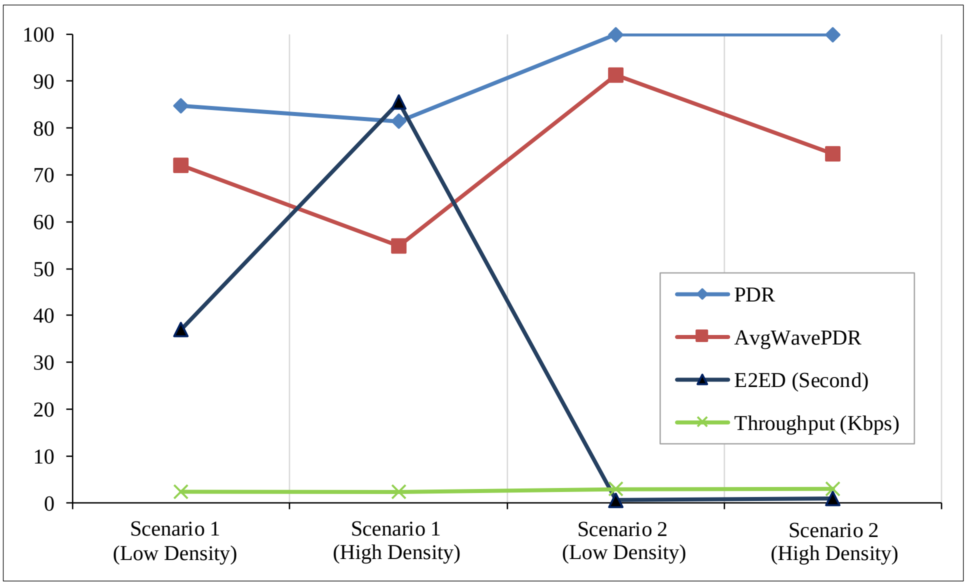

Figure 11. Overall Results for All Scenarios

Overall, the findings suggest that OLSR performs effectively in low-density VANET scenarios. The routing overhead and channel contention are lower in these environments, leading to improved PDR, reduced E2ED, and higher throughput. Conversely, high-density scenarios experience network congestion and routing complexities, which adversely impact performance metrics.

3.5. Comparison of Proposed Work with Existing Works

This study evaluates the performance of the OLSR protocol in realistic VANET scenarios, specifically in urban and highway environments using map data from Malacca, Malaysia. The study assesses OLSR's performance under two traffic densities (low and high) using the Wave and FlowMonitor modules in NS3. The results highlight that OLSR performs better in highway scenarios, where reduced congestion and fewer obstacles lead to higher PDR and throughput, compared to urban environments where higher node density causes congestion, leading to lower PDR and increased E2ED. These findings provide insights into the protocol's suitability for different network topologies and traffic conditions.

In contrast, several studies have evaluated OLSR performance but with different focuses and methodologies. Pratama et al. (2021) explored the impact of various propagation loss models on OLSR performance in VANETs, but their study did not account for traffic density or compare performance in urban versus highway environments. While their results were valuable for understanding how different models affect network performance, they did not provide the same level of insight into OLSR's feasibility in real-world dynamic traffic conditions. Similarly, Deshpande et al. (2019) compared OLSR with other protocols such as AODV, DSR, and GRP but focused on throughput and latency without addressing the specific effects of node density or urban versus highway settings on OLSR performance. These studies focused more on theoretical and control message overhead comparisons rather than providing insights into the real-world performance of OLSR under variable traffic densities.

Other studies, such as Shobana & Raj (2021) and Hota et al. (2022), are to some extent closer in their focus on realistic scenarios. Shobana and Raj (2021) applied an Intelligent Swarm-based Firefly Algorithm (ISFF) to AODV and compared it with OLSR-PSO in terms of QoS improvements, while Hota et al. (2022) conducted simulations in a real-world environment using SUMO and OpenStreetMap. However, their work primarily focused on protocol enhancements and algorithmic optimizations, rather than a detailed comparison of highway and urban environments or an in-depth analysis of traffic density's effect on OLSR. Thus, while these studies provide valuable contributions to OLSR's performance, they do not offer the same comprehensive comparison of OLSR's feasibility in different real-world settings, which is the primary contribution of this study.

While previous works have explored various aspects of OLSR performance, including propagation models, QoS optimizations, and protocol comparisons, this study differentiates itself by focusing on real-world traffic conditions and evaluating OLSR in both urban and highway environments under dense and sparse traffic conditions. The findings emphasize the importance of scenario-specific configurations and routing mechanisms, especially for urban environments with high node density.

4. Conclusions and Future Works

In summary, this study evaluated the Quality of Service (QoS) of the Optimized Link State Routing (OLSR) protocol in Vehicular Ad Hoc Networks (VANETs) through simulations conducted using NS-3 and SUMO. The simulation setup involved the creation of realistic traffic scenarios in different environments, including Malacca City Centre and a straight highway. SUMO effectively generated trace files that represented real-world traffic patterns, which were then imported into NS-3 for network simulation. Visualizations of PDR, E2ED, and throughput metrics enabled a clear comparison between scenarios, revealing that OLSR performs significantly better in highway scenarios than in complex urban environments. The findings indicate that OLSR is more suitable for highway scenarios, where lower E2ED and higher PDR can be achieved due to less network congestion and simpler routing paths. While the study provided insights into the performance of OLSR, several limitations emerged, particularly in high-density urban scenarios. The increase in E2ED and the decline in PDR in these environments suggest that OLSR struggles with the routing overhead and channel contention that come with complex city landscapes. For instance, the E2ED in the high-density Malacca City Centre scenario reached 85.52 seconds, making it unsuitable for real-time communication in safety-critical applications. Similarly, the low PDR of 81.40% highlights a high packet loss rate, which further diminishes the reliability of OLSR in dense environments.

To address the limitations identified, our future work will focus on optimizing OLSR's performance across different VANET scenarios. One primary area for improvement involves modifying OLSR's routing parameters to better match the specific environmental conditions. However, static parameter adjustments may not sufficiently accommodate variations in node density and network topology. Therefore, the implementation of artificial intelligence (AI) is recommended to enhance OLSR's adaptability. Machine learning (ML) or deep learning (DL) models, such as reinforcement learning or neural networks, could be incorporated into OLSR to predict optimal routing parameters based on network conditions. For example, a reinforcement learning model could learn to adjust parameters by rewarding lower delays and higher packet delivery ratios, adapting to both urban and highway environments in real time.

By leveraging AI, OLSR could dynamically adjust its routing parameters based on real-time network conditions, ensuring reliable packet delivery in high-density environments. To manage computational overhead, lightweight ML models or edge computing strategies could be implemented to minimize latency and maintain real-time performance. Additionally, future research could explore integrating AI with other routing protocols to determine whether similar performance improvements can be achieved. To validate AI-enhanced OLSR in real-world vehicular environments, our focus is to conduct field trials using connected vehicles equipped with low-latency edge computing devices. However, challenges may occur that include hardware limitations, network latency, and ensuring model robustness across different urban and rural landscapes.

5. Declarations

5.1. Author Contributions

Conceptualization, S.Y., S.F.A.R., and A.A.; methodology, Y.Y.X., M.S.S., and S.K.; software, Y.Y.X., and M.F.A.A.; writing—original draft preparation, Y.Y.X., S.F.A.R., M.F.A.A., and A.A.; writing—review and editing, S.Y., M.S.S., and S.K.; visualization, Y.Y.X. and S.Y.; funding acquisition, S.Y.; supervision, S.Y. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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5.5. Institutional Review Board Statement

Not applicable.

5.6. Informed Consent Statement

Not applicable.

5.7. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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