Fall 9-1-2022

Studying Routing Issues in Vanets Using Ns-3 and SUMO

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Abstract —Vehicular Ad-hoc Networks VANETs are normally sparse, highly dense, and highly mobile with many different and ever-changing topologies. These characteristics impose a challenge on finding a routing algorithm that fits the requirements of such network. The aim of this work is to study the performance issues of VANETs under different scenarios using realistic mobility models. In this paper, a comparative study is done among Ad-hoc On- Demand Distance Vector (AODV), Optimized Link State Routing (OLSR) and position-based routing protocols, namely Greedy Perimeter stateless routing (GPSR), and Max duration Min angle GPSR (MMGPSR). The comparison is done using key quality of service QoS metrics such as average routing goodput, end-to-end delay, MacPhy overhead, and packet delivery ratio PDR. The study is conducted using Network Simulator 3 (NS3) and SUMO.

Index Terms—VANETs, SUMO, NS3, OLSR, AODV, GPSR, MMGPSR

I. INTRODUCTION

Vehicular ad-hoc networks (VANETs) fall under the umbrella of MANETs, though they are characterized by high mobility and rapidly changing topology. There are several proposed architectures for VANETs. as proposed in [1] a VANET consists of an ad-hoc plane, infrastructure plane, and network plane that connects the whole system to the internet and provides data to the other levels. The communication is conducted between vehicles via On-Board Units (OBUs) and a Roadside Unit (RSU) to connect the network to the infrastructure. As proposed in [2], vehicle to vehicle (V2V) communication could use IEEE 802.11P and for vehicle-to-infrastructure (V2I). Fig. 1 presents a basic VANET architecture showing its main components. Due to the rapid changes in their topology, VANETs cannot utilize conventional routing protocols used for static networks; therefore, researchers have developed and evaluated routing protocols for VANETs. In this paper, a comparative study between Ad-hoc On-Demand Distance Vector (AODV), Optimized Link State Routing (OLSR), Greedy Perimeter Stateless Routing (GPSR), and its variant MMGPSR with respect to Quality-of-Service (QoS) metrics. This study was conducted using Network Simulator 3 (NS3) [3] which has already the aforementioned protocols implemented. However, it does not support complex mobility models.

The main contribution of this paper is the use of the Simulator for Urban Mobility (SUMO) [4] in addition to NS3. SUMO is used to generate the mobility model of the vehicles according to a physical area with the roads and intersections clearly defined. Then, this mobility model is fed to NS3 in order to make the simulation more realistic. The rest of the paper is organized as follows, Section II contains background about VANETS, Section III discusses related work that was published in literature. Section IV details the simulations setup. Section V presents and discusses the results. Finally, Section VI concludes the paper.

Fig. 1. VANET Architecture. 1) Road Side Unit (RSU), 2) On Board Unit (OBU), 3) Vehicle-to-Vehicle Communication (V2V), and 4) Vehicle-to-infrastructure Communication (V2I).

II. BACKGROUND

This section gives a brief background on the main topics that are covered in this paper.

A. VANETs

Vehicular ad -hoc networks (VANETs) are created by applying the principles of mobile ad hoc networks (MANETs) to the domain of vehicles [5]. VANETs were first mentioned and introduced in 2001 [6] under “car-to-car ad-hoc mobile communication and networking” applications, where networks can be formed, and information can be relayed among cars on the move. It was shown that vehicle-to-vehicle (V2V) and vehicle-to-infrastructure V2I communications architectures must co-exist in VANETs to provide road safety, navigation, and other roadside services. VANETs are a key part of the intelligent transportation systems (ITS) framework. Sometimes, VANETs are referred as Intelligent

Manuscript received March 14, 20022; revised August 16, 2022.
doi:10.12720/jcm.17.9.682-690

Transportation Networks. They are understood as having evolved into a broader “Internet of vehicles” [7], which itself is expected to ultimately evolve into an “Internet of autonomous vehicles” [8].

While, in the early 2000s, VANETs were seen as a mere one-to-one application of MANET principles, they have since then developed into a separate field of research. By 2015, the term VANET became mostly synonymous with the more generic term, inter-vehicle communication (IVC), although the focus remains on the aspect of spontaneous networking, and much less on the use of infrastructure like Road Side Units (RSUs) or cellular networks [9].

B. Classification of Routing Protocol

Due to the very dynamic nature of Vehicular Ad-Hoc Networks, there is a variety of routing protocols that aim to solve routing issues that arise in VANETs. These protocols are categorized as follows:

- **Position Based Routing Protocol:** This class of protocols uses Global Positioning System (GPS), so nodes do not need a routing table to convey a message rather than have the positional coordinates of the target. Though the system not relying on a routing table is advantageous, it suffers from losing connection in tunnels [10]. Examples of these protocols are DREAM (Distance Routing Effect Algorithm for Mobility), and GPSR (Greedy Perimeter Stateless Routing). This class of protocols has had some attention, including Delay-Tolerant VANETs [11].
- **Topology Based Routing Protocol:** This class of routing protocols has three different categories.
  - **–Proactive Routing Protocols:** Where every node has a routing table so that whenever a node needs to send a message it can be conveyed through the other nodes via the routing table [10]. Examples of such protocols are Destination Sequenced Distance Vector (DSDV), and Optimized Link State Routing (OLSR).
  - **–Reactive Routing Protocols:** These protocols are labeled as being on-demand as the route is discovered whenever a node needs to send a message [10]. Examples of such protocols are Ad-hoc On- Demand Distanced Vector (AODV), Ad-hoc On- Demand Multipath Distance Vector (AODVM), and Dynamic Source Routing (DSR).
  - **–Hybrid Routing Protocols:** Combines the features of the two previous categories.

C. SUMO Simulator

Used for traffic modeling and simulations, SUMO is an open-source software package developed at the German Aerospace Center that aid in modeling and simulating traffic networks; these simulations could be used to research traffic management solutions, simulate vehicular communications, and implement autonomous driving scenarios. SUMO is considered to be a suite of applications. Each application servers a specific purpose, such as netgen and netconv packages [4]. With sufficient setup, SUMO could be used to generate traffic scenarios in, for example, a Manhattan grid with a specific number of vehicles and trips. SUMO also allows researchers to adjust the network depending on the nature of the required topology. Additionally, SUMO can use Open Street Map (OSM) to generate traffic scenarios for real-world road maps, which further enriches the capability of this simulation suite.

D. NS-3

Licensed under the GNU GPLv2 license, NS-3 is a discrete-event simulator for communication networks, aimed mainly for research. NS-3 is built using C++ as libraries [3]. and the software is organized as shown in Fig. 2.

- **Core**: contains events, schedulers, time arithmetic, and responsible for logging, callbacks, and processing other random variables in the system.
- **Network**: contains packets, packet tags, packet headers, and ASCII file writing, it is also reps for setting a node class and address, IPv4, MAC, etc.
- **Mobility**: controls mobility models of the nodes (static, random, walk, etc).
- **Helpers**: high-level wrappers that are aimed at scripting (wifiHleper, AODVHelper, etc).

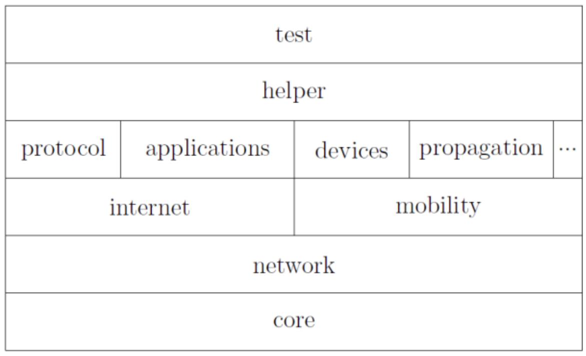


Fig. 2. NS3 Software Architecture.

In this paper, we will be using NS3 to simulate the network and alanyze the performance of the routing protocols. While SUMO is used to generate the mobility model of the nodes.

III. Related Work

Bala and Krishna in [2] presented a comparative study between AODV and GPSR using NS2 under different scenarios. They have also experimented with changing the Mac/Phy layer in cluster-based simulations under urban settings, making the following key observations. For Packed delivery Ratio (PDR), both protocols performed badly given a low number of vehicular nodes. However, GPSR performed consistently better for PDR. The authors have also compared the performance under 802.11p and 802.11 technologies; using both UDP and TCP traffic. It is worth noting that they used a relatively low number of vehicles in urban scenarios compared to what is going to be presented by this paper.

Ema *et al*. in [12] made a comparison between AODV, AOMDV a modified version of AODV, DSR, DSDV, and GPSR. The comparison was based on changing the number of nodes present in the network also by changing the velocity of the nodes and studying the effect of both. They concluded that AOMDV has the highest end to end delay while DSDV had the lowest for all number of nodes; the same result was repeated for the routing load of the network and the throughput; the other protocols maintained an average between AOMDV and DSDV. Noting on the simulation setup, they employed a number of nodes from 20 to 80 and velocities from 10 m/s to 90 m/s. Our work does a similar analysis but with higher velocities, and higher densities.

Chouhan and Deshmukh presented in [13] a comparative study using NS3 between AODV, DSDV, and OLSR. The comparison was done using packet delivery ratio, and packet loss ratio as metrics. The study used a static number of OBUs and RSUs to represent the VANET, a multi-lane unidirectional mobility model and a Nakagami radio propagation model. For RSUs, DSDV had a consistent result but relatively higher than the other two protocols. Regarding PDR, DSDV performed worst, and OLSR had the highest packet delivery ratio. Our work uses a more complex mobility model generated from SUMO and not limited by NS3 mobility models.

Mantoro and Reza in [14] used NS2, MOVE, and SUMO to study the performance of both AODV and DSDV. The study used a static number of nodes and an Omni antenna model with two-lane traffic. The performance metrics used was throughput and End to End Delay. The results have shown that AODV had better throughput, while DSDV had a lower end to end delay as AODV is a reactive routing protocol. Our work expands on this by using NS3 and adding more protocols and more metrics to the study.

Hamid and Mokhtar in [15] conducted an extensive study on AODV, DSDV and OLSR using NS2 and SUMO. The study included varying node number and varying node speeds in an urban environment. The study's outcome by varying node speed was that OLSR had the least delay, while AODV had the highest packet delivery ratio and the highest bandwidth. However, when the node number was varied, OLSR had lowest delay, while AODV had the highest packet delivery ratio and the highest throughput. This work will be using NS3 as it is more flexible in programing and has an updated routing protocol base.

In [16], Kashyap *et al.* conducted a comparative study on AODV and DSR routing protocols using NS2 simulator. Key parameters used for evaluation in this contribution was End to End delay, Throughput, and packet delivery ratio. AODV achieved the lowest end to end delay and the highest packet delivery ratio. At the same time, DSR had the highest Throughput. DSDV performed quite similar to AODV regarding the end-to-end delay; however, it had a significantly worse packet delivery ratio.

Vijaya and Rath in [17] presented a study on the performance of AODV, DSDV, and DSR routing protocols in a TCP and UDP environments. The simulations were performed using NS2. The study suggested that as the number of nodes increases, the performance of AODV starts to surpass that of DSR. However, the study indicates that DSR imposes lower loads on the network for routing.

Chekima *et al.* presented in [18] a performance study on several routing protocols such as AODV and DSR from the reactive routing protocols and OLSR a proactive routing protocol using NS3 and SUMO simulator. In their work, they used IEEE 802.11p, with a varying number of vehicular nodes from 20 to 100 nodes, with a two ray ground, Nakagami propagation loss model; they have also used UDP transport protocol and a packet size of 512 bytes. They concluded that AODV performs better than the other two protocols in the following QoS metrics Throughput and Delay. This work follows a similar model but with more routing protocols and more variation in the topology.

Mouhib *et al.* presented in [19] a performance comparison between Q-AODV and GPSR in a realistic city map using NS3 and SUMO simulator in a Network as a Service of the vehicular ad-hoc network in a vehicle-to-vehicle communications. The Q-AODV discussed in this work is a stateless routing protocol where resources availability is only checked whenever there is a transmission taking place. This paper also further asserts the claim in our paper that GPSR is not a great choice for a city topology as it performs best under highway scenarios. This work used the following parameters for their simulation's environment size was set to 2000 meters X 2000 meters with 100 nodes and UDP traffic and assumed a MAC layer IEEE 8051. The results were that GPSR had better PDR than AODV. Also, GPSR had a better end to end delay, AODV has a smaller number of packets lost, and finally, GPSR had higher throughput.

In [20], Bengag *et al.* presented a methodology to enhance GPSR routing protocol in terms of throughput and packet delivery ratio in addition to reducing the routing overhead of the position-based routing protocol. They proposed several optimization techniques to reach the proposed performance. In this paper, they used NS3 and SUMO simulators to conduct simulations in an urban environment with the following parameters; simulations had ten destinations with random selection. The number of the vehicular nodes used was 30, 50, 70 and 90 nodes with a speed of 20m/s with a simulation duration of 200 seconds. The area of the simulation was 1.7Km * 1.5Km, the data packet size used is 512 bytes with a constant bit rate UDP traffic, and a two-ray ground propagation model. They assumed an IEEE 802.11p MAC layer. The three protocols simulated, GPSR, DVA-GPSR, and E-GPSR performed as following for PDR, DVA-GPSR performed best, while GPSR performed worst with an increasing number of nodes. While for the throughput, E-GPSR performed best and GPSR again the worst overall number of nodes present in the network and lastly, GPSR had the highest overhead while DVA-GPSR had the least routing overhead.

In [21], Setiabudi *et al*. presented a comparative study using NS2 on performance of GPSR and ZRP. The study metrics are throughput, packet delivery ratio, end-to-end delay, and number packet loss. In all metrics but the number of packets lost and packet deliver ratio, GPSR proved superior.

Naim and Hossain in [22] conducted a performance evaluation for AODV, DSDV, and DSR routing protocols. The assessment was based on typical QoS metrics. The traffic type used was TCP. They concluded that AODV has superiority over the other protocols in a parameter such as throughput for static and mobile networks. Simultaneously, DSDV suffered less from link losses, and DSR had the least delay and jitter.

IV. Simulation Setup

This section presents the simulation setup used to analyze the four routing protocols under investigation which are: the reactive routing protocol AODV, the proactive routing protocol OLSR, and the two position-based routing protocols GPSR and MMGPSR.

The Manhattan grids are studied heavily in literature when it comes to VANETs this one reason we chose it as a topology for our simulations, and the second reason is that there are some desirable properties in the Manhattan grid that we exploit in the study, in addition to that, we have also made some assumptions. The Manhattan grid designed for the final simulations is shown in Fig. 3, and it is characterized as follows, it is a 2000-meter by 2000-meter square grid having five intersections in the middle and is divided into eight blocks. The y-direction blocks are 1000 meters while the x-direction blocks are 250 meters.

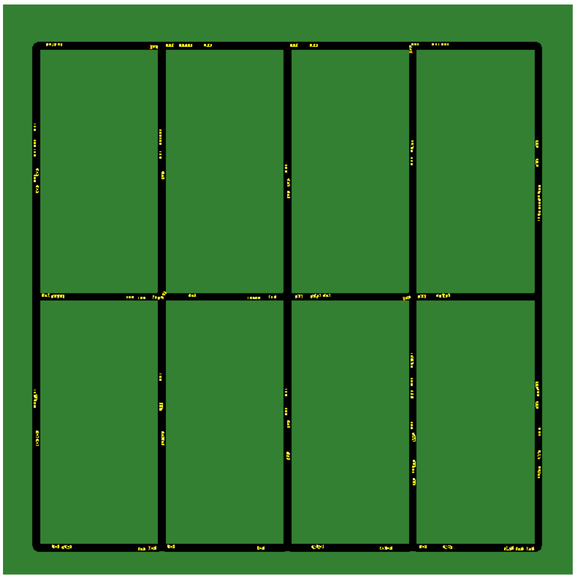


Fig. 3. Grid layout with various traffic densities in SUMO simulation, density:110.

Moreover, Fig. 4 shows the simulation in NS3 after importing the mobility model from SUMO. We assumed that the grid has two lanes in each direction, and at each of the priority intersections, the vehicle could proceed forward, turn left, turn right, or make a U-turn, as shown in Fig. 5; this enables us to make SUMO reroute vehicles for the entire duration of the simulation.

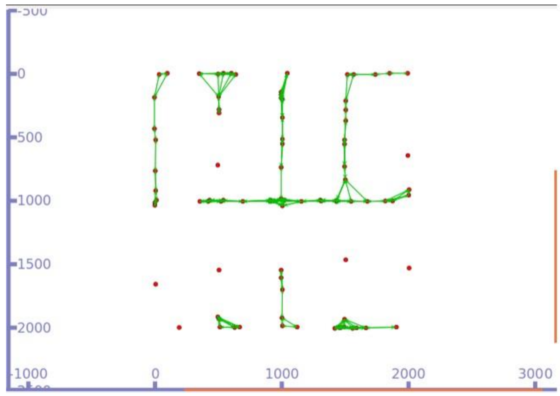


Fig. 4. Grid layout with various traffic densities in NS3 simulation using pyViz, density:90.

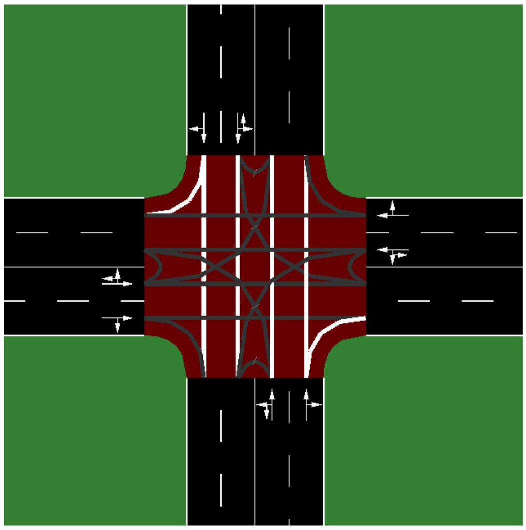


Fig. 5. Intersection created in SUMO, showing directions and rules of the intersection.

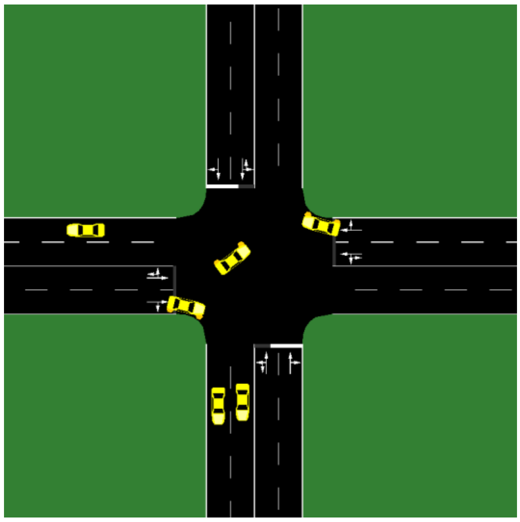


Fig. 6. Intersection created in SUMO showing the intersection in action.

The behavior of the vehicles is shown in Fig. 6 with each vehicle taking the path selected by the simulator. The Manhattan grid has many features and is studied in [23]. However, we are only interested in the gridlock at the intersection; as we will show later, it will enable us to simulate semi clustered networks.

The experiment is set up to achieve a 90 percent confidence interval by repeating each scenario multiple times using different random seeds for each iteration of the simulations. Each protocol is tested under increasing node density scenarios. Then these scenarios are repeated for multiple numbers of connection pairs. Detailed experiment setup is shown in Table I. The mobility model was created using SUMO and imported to NS3. The analysis and measurement were done using NS3's Flow monitor presented in [24]. The metrics used for the comparison are mainly:

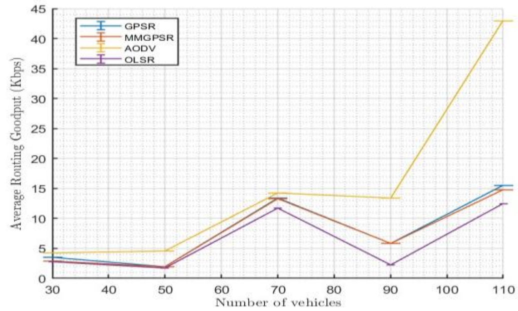
TABLE I: SIMULATION SETUP

Parameter	Value
Protocols	AODV OLSR GPSR MMGPSR
Number of connection pairs	5,10,15,20
Number of Nodes	Start 30 Step 20 STOP 110
Number of Random Seeds	20
Mobility Model	SUMO generated Manhattan grid
Area	2000m X 2000m
Node Speed	50 kph
Application Data Size	512 Bytes
Simulation Time	200 Seconds
Traffic Type	UDP
WAVE Phy	802.11p
phyMode	OfdmRate3MbpsBW10MHz
Propagation Model	Two Ray Ground Propagation Loss

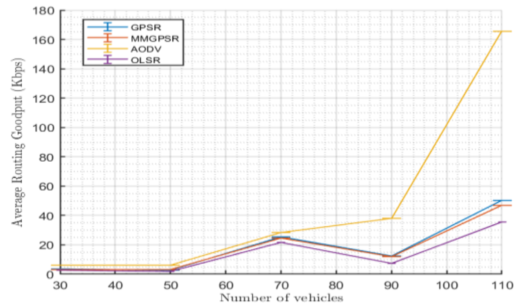
- **Average Goodput**: The number of useful information bits delivered by the network to a certain destination per unit of time.
- **MacPhy Overhead**: The MAC/Phy layers overhead that the routing protocol adds to the communication.
- **Mean Tx Packet Size**: The average size of all the transmitted packets. Which includes both data and routing packets.
- **Packet Delivery Ratio**: The number of correctly received packets divided by the total number of transmitted packets.

V. RESULTS

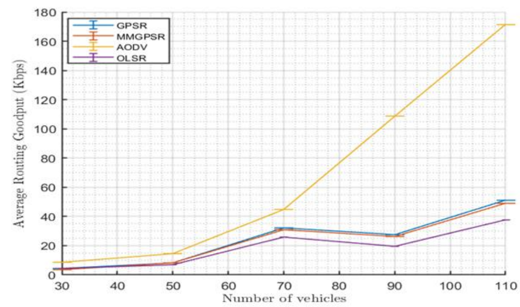
Average Goodput (Kbps), is the actual data size that was sent after the process of routing; hence this metric is key in classifying routing protocols performance. Fig. 7 shows the average goodput for the result among multiple values of connection pairs. As we can see from the results, AODV maintained the highest Goodput among all other protocols, with the margin widening at higher loads and higher network density. This is because AODV is based on Dijkstra's shortest path routing, which decreases the overhead at higher node densities. All protocols reached their highest goodput rates at 110 nodes, with AODV having 45Kbps, 165Kbps, 170Kbps, and 226Kbps and the OLSR came last with 12Kbps, 35Kbps, 39Kbps and 40Kbps for 5, 10, 15, and 20 connection pairs, respectively. GPSR and MMGPSR being relatively similar protocols, their values were relatively the same, with MMGPSR only slightly better at low densities for high load networks.



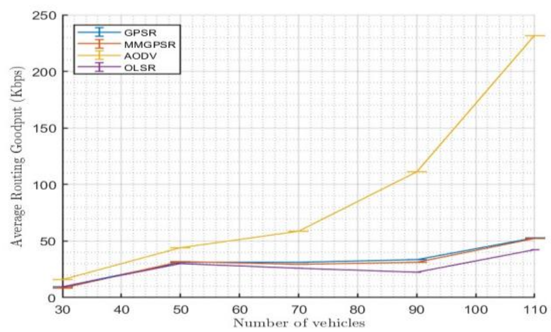
(a) 5 Connection Pairs.



(b) 10 Connection Pairs.

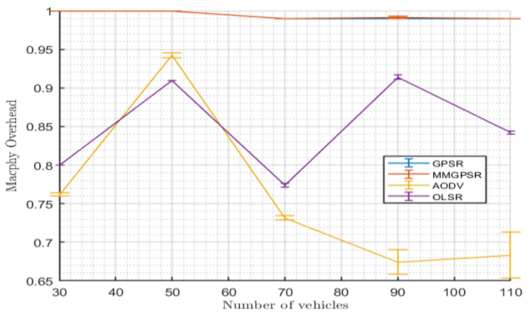


(c) 15 connection pairs.

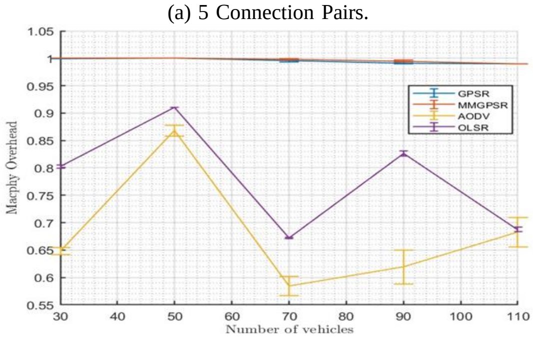


(d) 20 connection pairs.

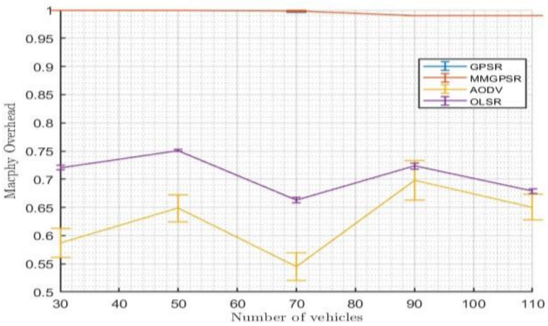
Fig. 7. Average Goodput (Kbps) at different loads a) 5 connection pair, b) 10 connection pair, c) 15 connection pair, d) 20 connection pair.



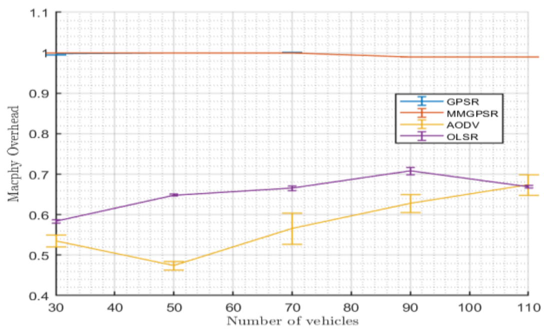
(a) 5 Connection Pairs.



(b) 10 Connection Pairs.



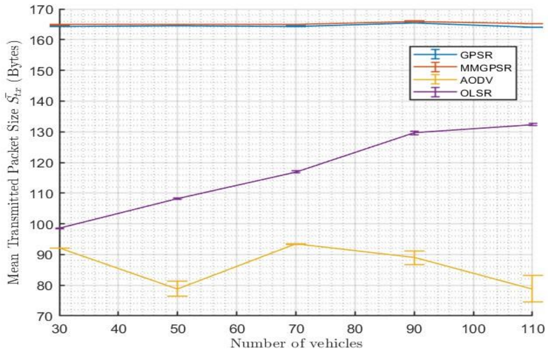
(c) 15 connection pairs.



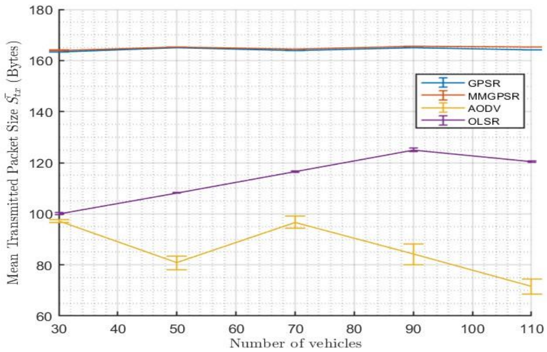
(d) 20 connection pairs.

Fig. 8. MacPhy overhead at different loads a) 5 connection pair, b) 10 connection pair, c) 15 connection pair, d) 20 connection pair.

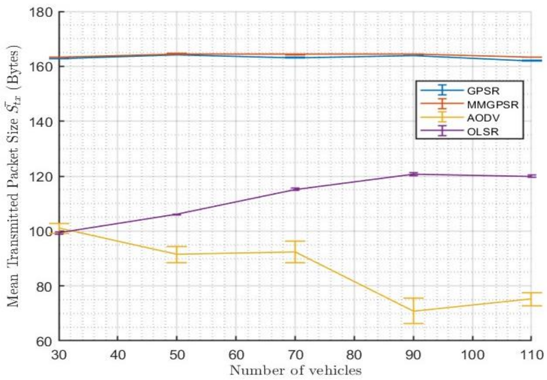
The MacPhy Overhead shows the percentage of routing packets to data packets and gives us an insight into how efficiently a protocol manages the physical layer. A prominent feature of the data presented in Fig. 8 is that both GPSR and MMGPSR have very high MacPhy overhead, especially at low densities where nodes could remain isolated for an extended period sending beacons. Nevertheless, for higher densities, the MacPhy overhead for both protocols starts decreasing slightly. However not nearing the efficiency of AODV and OLSR because of the time they spend forwarding in perimeter mode.



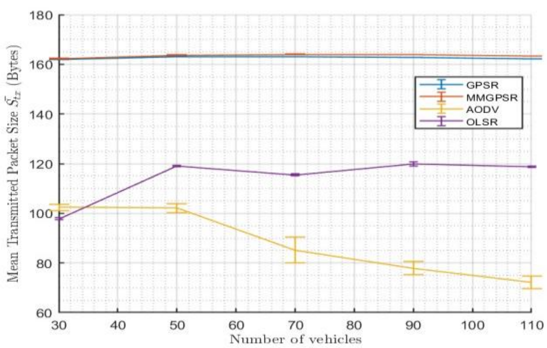
(a) 5 Connection Pairs.



(b) 10 Connection Pairs.



(c) 15 connection pairs.



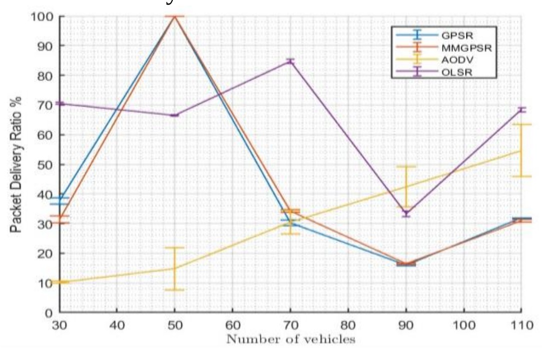
(d) 20 connection pairs.

Fig. 9. Mean Tx packet size (Bytes) at different loads a) 5 connection pair, 10 connection pair, c) 15 connection pair, d) 20 connection pair.

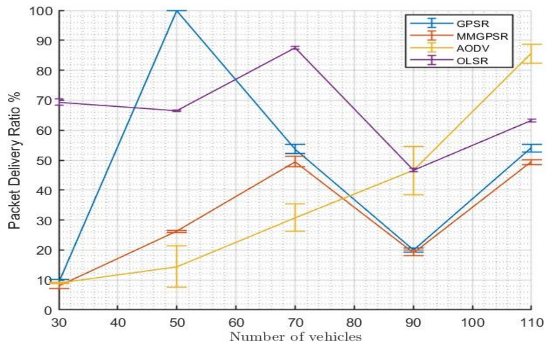
At the same time, AODV performed notably better than OLSR under most scenarios except at 50 nodes in a five-connection pair network and 110 nodes in a 10 and 20 connection pairs network where the two protocols exhibited the same overhead 0.68 with OLSR having higher confidence over the value. This behavior is because OLSR scales well with the increasing source to destination pairs. However, AODV starts to struggle with the rise of the active routing queries for a higher number of connection pairs.

The mean transmitted packet size includes both data packets and routing packets. However, in the case of GPSR and MMGPSR, it is vital to note that they use a piggybacking approach to transmit beacons where beacons are piggybacked on data packets [25]. From Fig. 9, we observe that AODV has the smallest mean transmitted packet size except at 30 nodes in 15 and 20 connection pairs network where OLSR is only slightly smaller. We also observe that AODV has a dominating downtrend while OLSR has an uptrend with saturation with respect to node density. Where AODV has the highest values of 95, 98, 100, and 110 Bytes while OLSR saturates at 132, 125, 120, and 120 Bytes for 5, 10, 15, and 20 connection pairs, respectively for both protocols. We also notice that unlike the trend with node density, AODV has an uptrend while OLSR has a downtrend; this further asserts the aforementioned issue that AODV suffers from with the increasing number of connection pairs. We also notice that the decrease in node density causing the decrease in transmitted packet size is met with a significant rise in Goodput shown in Fig. 7. At the same time, GPSR and MMGPSR maintained a relatively constant packet size at slightly higher than 165 Bytes.

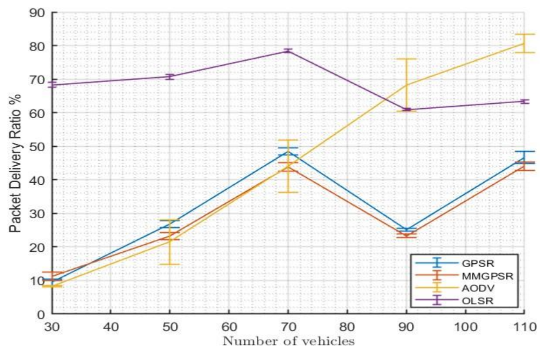
The packet delivery ratio is an important metric used to determine if a given protocol is suitable for specific applications that require reliable transmission of data. Shown in Fig. 10 is the PDR of the routing protocols under test with varying node densities and connection pairs. A prominent feature in the presented data is the very high PDR for GPSR and MMGPSR at a low network load. We also notice that in a low network load for medium traffic density, MMGPSR exhibits better performance than GPSR. The second prominent feature is that both GPSR and MMGPSR have better performance than AODV in low and medium traffic density scenarios. However, AODV exhibits a consistent increasing performance overall network load scenarios. At the same time, OLSR exhibited mostly consistent performance surpassing most protocols for low and medium density networks in a medium load scenario. We also note the presence of an uptrend for GPSR and MMGPSR after 90 nodes traffic density.



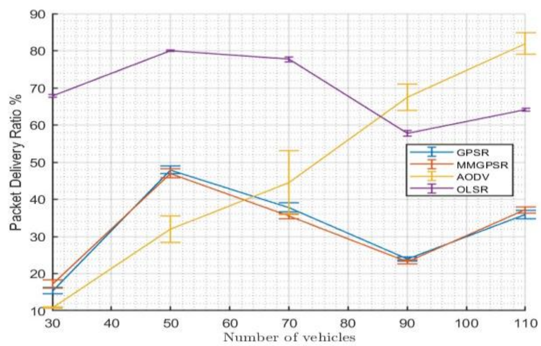
(a) 5 Connection Pairs.



(b) 10 Connection Pairs.



(c) 15 connection pairs.



(d) 20 connection pairs.

Fig. 10. PDR at different loads a) 5 connection pair, b) 10 connection pair, 15 connection pair, d) 20 connection pair.

VI. Discussion

In this section, we present a discussion of the results that were presented in the previous section.

We have analyzed the routing protocols using several QoS metrics starting by analyzing the average routing Goodput for each routing protocol and observed that AODV performed better than all other protocols over all network densities and loads, while OLSR performed worst.

For the MacPhy overhead. In all the scenarios, AODV performed notably better than the other three protocols except in high-density medium and heavy load network scenarios where OLSR starts to have the same overhead as OLSR scales well with the increase in the source-destination pairs, while AODV's performance decreases with the rise of the active routing queries. This metric also shows the very high overhead of the protocols GPSR and MMGPSR, especially at lower densities where nodes can remain isolated for an extended time.

For the mean transmitted packet size. The presented data have an evident trend for all protocols where GPSR and MMGPSR had a very high mean transmitted packet size compared to the other two protocols, where we noted that GPSR uses a piggybacking method for transmitting beacons and that the data is piggybacked on top of the data packets holding the location of the sender node. At the same time, AODV exhibited a downtrend with the increase in node density. However, it experienced a very slight increase in the mean transmitted packet size with the increase of the network load, for a reason mentioned before that AODV struggles with the increase of the ongoing routing queries. In contrast, OLSR has shown an increasing trend with saturation with increasing the number of nodes and a decreasing trend with the decreasing number of nodes.

The last metric used was the PDR. AODV had the lowest PDR in low-density networks for all loads. However, AODV starts to break even with the other protocols at medium density networks with an uptrend that indicates the scalability of AODV with the increasing size of network topology. At the same time, OLSR has shown reliable PDR with low and medium density networks due to the use of MPR; in contrast, GPSR and MMGPSR have shown PDR higher than AODV for low-density networks, with MMGPSR being better than GPSR only in low load network scenarios.

VII. Conclusion

This paper presented novel research aimed at studying and comparing the topology-based routing protocols AODV and OLSR to the position-based routing protocols GPSR and MMGPSR in real life VANET mobility model imported from SUMO simulator. An extensive simulation plan was compiled where simulations for each of the four protocols were conducted by varying the node densities and the number of connection pairs. Each simulation was repeated 20 times using 20 different seeds to obtain a 90 percent confidence interval for the results. We have observed and analyzed the behavior of the four protocols in a Manhattan grid created using SUMO simulator. Four QoS metrics were used in the study, namely, Average goodput, Mac/PHY overhead, Mean TX packet size, and packet delivery ration. AODV was shown to outperform the other protocols in almost all the metrics other than PDR and scenarios for low to medium densities. While OLSR outperforms in terms of PDR in low densities.

Conflict of Interest

The authors declare no conflict of interest

Author Contributions

Mohammad M. Abdellatif: formulating the idea, designing the experiments, writing and editing the paper, presenting and discussing the results Omar Aly: literature review, performing the experiments, collecting and presenting the results, writing the paper

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