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Evaluating End-to-End Delay in Road-Based Routing Protocols for VANETs using Snake Optimization

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ABSTRACT: Routing in Vehicular Ad hoc Networks (VANETs) becomes complicated with frequent changes in the network topology and high node mobility, which leads to higher end-to-end delay (EED) and deteriorated network performance. Conventional routing protocols such as AODV, DSR, GPSR, OLSR, DSDV and WRP do not ensure reliable paths due to the frequent change in the topology resulting in unreliable connections and varying link durations. This instability directly affects the EED as paths with more stable connections tend to have lower delays. To overcome these challenges, we introduce the Road-Based Vehicular Traffic (RBVT) routing technique, which incorporates Reactive RBVT-R and Proactive RBVT-P routing protocols to achieve path stability and minimize EED. In addition, the Snake Optimization Algorithm (SOA) is incorporated into RBVT so as to improve the routing decision based on the number of hops and connection stability. Our quantitative assessment proves that the proposed SOA-RBVT approach has better performance than existing protocols in terms of EED even under high vehicular density. Therefore, this work demonstrates the effectiveness of the SOA-RBVT model in enhancing the reliability and continuity of VANETs while addressing the problem of high mobility and dynamic topology in the network.

Keywords: End-to-End Delay (AEED), VANETS, Snake Optimization Algorithm (SOA), Packet Delivery Ratio (PDR)

1. INTRODUCTION

Vehicular Ad Hoc Networks are a specialized type of communication network that targets applications such as intelligent traffic management systems and safety enhancements. These networks face significant challenges related to network scalability and topology, primarily due to the high mobility of nodes and the sparse distribution of vehicles on roads. Key issues include the construction of a physical layout and the instability of links, which must be addressed to ensure robust, reliable, and scalable communication, particularly in densely populated traffic networks. The growing importance of Vehicular networks in developing advanced transportation systems has attracted considerable interest from researchers. These networks possess several distinctive features, including rapid movement, network fragmentation, sporadic disconnections, and urban obstructions, all of which present challenges for routing. Backbone routing is often employed in these networks due to their inherent characteristics [1-3].

Wireless communication plays a crucial role in VANETs, as timely data exchange requires the establishment of rapid and resilient network connections. The importance of routing protocols in these networks cannot be overstated; they are essential for establishing and maintaining links between source and destination locations. Some of the most critical characteristics of this type of networks include [4-6]:

- **Dynamic Topology**: Nodes typically move at high speeds, leading to a constantly changing network topology. This dynamic nature makes accurately determining a node's position a complex task. There is frequent information exchange, with nodes actively gathering data from other vehicles and roadside equipment, increasing the frequency of information sharing.
- **Wireless Communication:** Designed to function in a wireless environment, these networks facilitate the connection and exchange of information between vehicles. A specific level of security is required to ensure safe

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*Corresponding author: 865.hamid@gmail.com communication. The implementation of VANETs can be scaled to cover multiple cities or even entire countries, indicating no geographical limitations to the network size.

The primary goal of Ad Hoc Vehicular Networks is to provide safe information dissemination. However, due to the rapid changes in network topology and the self-organizing nature of these networks, link failures can occur. If communication fails, there is a significant risk of severe harm. Therefore, it is crucial to establish a highly efficient and high-quality network to maintain a high level of safety for drivers [7].

2. VANET ROUTING PROTOCOLS

Given the high mobility characteristic of VANETs, the selection of an appropriate routing protocol becomes a significant consideration. Network packets are transmitted between cars that are in motion at varying speeds, and the density of vehicles fluctuates. This dynamic situation poses challenges for routing algorithms, due to the highly demanding nature of VANETs. In wireless vehicular networks, routing protocols are used to route and exchange data between vehicles and infrastructure. There are two main types: reactive and proactive. Reactive protocols respond to network changes, like AODV and DSR, and exchange information based on requests and environment changes. Proactive protocols, like OLSR and DSDV, build and maintain routing tables in advance, updating them regularly without immediate requests. Developers must choose the appropriate protocol that meets network requirements and provides reliable and efficient data exchange performance in VANET environments[9].

3. RELATED WORKS

P. Shah and T. Kasbe's [9] the paper compares proactive and reactive protocols in VANET, evaluating UMB and BROADCOMM performance. They emphasize the importance of reliable routing protocols for high-speed environments with multiple vehicles. The study focuses on improving packet delivery rate, reducing interference, managing conflicts, and ensuring timely data packet delivery. Simulation results were based on AODV, DSR, and swarm intelligence protocols, evaluating average end-to-end delay in VANET routing protocols.

In their work,[10]the article compares various location-based routing protocols in vehicular networks, including GPSR, DSR, GSR, FANET, LBGR, GPSR, and PSOR. GSR outperforms AODV and DSR in terms of PDR and latency, while GPSR delivers 94% of data packets effectively. PSOR improves PDR, reduces overhead, and increases forwarding node position accuracy. The NS2/SUMO model was used to simulate these protocols. Despite their effectiveness, they face challenges like local optimum problems, inaccurate positioning, optimum forwarder selection, and broadcasting overheads. Future work could involve implementing these protocols in a VANET environment, analyzing obstacles in urban scenarios, and using mathematical modeling to evaluate results.

One such contribution presented by [11], researchers compared three VANET routing protocols: AODV, DSDV, and OLSR, evaluating their performance based on parameters like packet delivery ratio, packet loss ratio, and throughput. AODV was found to be the most optimal method, with a 48% PLR and 30% PLR for DSDV and OLSR protocols, respectively. The study suggests that routing protocols can yield better outcomes based on factors like mobility, density, and network size.

The study [12], evaluated communication routing protocols in VANETs between autonomous and human-driven vehicles in Madinah city using three ad hoc protocols: AODV, DYMO, and DSDV. It found that fully autonomous traffic distribution reduced trip time by 100%, 92.7%, and 91.1% compared to human-dominated, mixed, and autonomous-dominated scenarios. Communication latency between autonomous vehicles showed almost identical performance. The study concluded that routing protocols could be selected based on traffic density, distributions, and scenarios. The simulation platform used was an integrated tool combining network simulator OMNeT++, communication protocol library INET, vehicular network simulation library Veins, and road traffic simulator SUMO.

In the paper [13], the researcher performed a comparison of QoS routing protocols studied according to a set of basic QoS parameters used to optimize routing protocols and the different QoS metrics. The comparison is carried out according to other criteria, such as offered QoS, MAC protocol, Applications, etc. Nearly 90% of the surveyed protocols have implemented their propositions and evaluated their performances. The common simulators used are NS2, OMNet++, MATLAB, SUMO, etc. Most of the proposed protocols have been tested in an urban environment. The researcher concluded that QoS performance is achieved, and a comparison of all QoS routing protocols has been done. The researcher has based his simulations on VANET simulation environments.

In the research [14], the QTAR (RSU-Assisted Traffic-Aware Routing) protocol is compared with GPSR, LAR, GyTAR, iCar-II, and RTAR. The comparisons are based on two main performance metrics: Average Packet Delivery Ratio (APDR) and Average End-to-End Delay (AEED). QTAR improves APDR by 9.85% compared to RTAR, 12.8% compared to iCar-II, and 21.14% compared to GyTAR. It also reduces AEED by 4.22% compared to iCar-II, 18.68% compared to RTAR, and 45.94% compared to GyTAR.The research concludes that QTAR outperforms other protocols in both APDR and AEED metrics, considering Link Expiry Time (LET) and joint R2R and V2V learning strategies to improve packet delivery efficiency and reduce delays. Simulations were conducted using QualNet and VanetMobiSim, evaluating APDR and AEED in an urban VANET scenario with specific parameters like vehicle count, speed, CBR flows, and data generation intervals.

Authors in [15] Enhanced Hybrid Ant Colony Optimization Routing Protocol (EHACORP) significantly improves routing efficiency in Vehicle Ad-hoc Networks (VANETs) by reducing ant search time, improving convergence speed, avoiding blind broadcasting, faster packet processing, and avoiding stagnation problems. The study used the NS 2.34 simulation tool to compare EHACORP's performance with F-ANT, ARA, AODV, and AntNet protocols, resulting in improved Packet Delivery Ratio (PDR), Packet Loss Ratio (PLR), and Throughput.

The researcher in[16] compared the performance of AODV and GPSR routing protocols in VANET using three different scenarios: changing the number of vehicles while maintaining a constant speed of 40 km/h, changing the speed value while maintaining a constant number of vehicles, and changing the communication range while maintaining a constant speed. The results showed that AODV had better Packet Delivery Ratio, while GPSR had better End-to-End Delay. The study used OMNeT++ and SUMO for simulation purposes.

Authors in [17] the study on the Enhanced Snake Optimizer (SNDSO) showed significant improvements in optimization efficacy compared to the original Snake Optimizer (SO). The SNDSO algorithm demonstrated greater convergence performance, global optimization capabilities, and stability in complex optimization issues. It outperformed other algorithms in discretized, high-dimensional, and multi-constraint problems, demonstrating its effectiveness in various optimization situations.

The Snake Optimizer algorithm was studied and enhanced, leading to the creation of the Improved Snake Optimizer algorithm (ISO). This method improves search capabilities and stability by incorporating techniques like Chaotic mapping, dynamic development probability modification, and Levy flight updates. The ISO algorithm outperforms the Snake Optimizer in convergence speed, accuracy, efficiency, and stability [18].

The researchers in [19] introduced a novel technique, known as compact snake optimisation (cSO), which demonstrated superior efficiency in addressing intricate optimisation problems when compared to other established algorithms. The cSO method is highly efficient in minimising positioning mistakes in indoor positioning, as demonstrated by simulated trials. The research findings suggest that the cSO method may greatly enhance the efficiency of WKNN fingerprint positioning and RSSI positioning, which are utilised for WSN localization.

4. ROAD-BASED VEHICULAR TRAFFIC PROTOCOLS

Road-based vehicular traffic (RBVT) is implemented uniquely by applying the Reactive on-demand routing protocol (RBVT-R) and the Proactive protocol (RBVT-P) within a single framework. The Reactive on-demand routing protocol (RBVT-R) is utilized as a reactive routing mechanism for VANETs. Routes are created on-demand using geographical links between road sections at adjacent intersections. These interconnected paths are contained in the headers of user data packets. Packets are moved between junctions by medial junctions. The RBVT-R system is well-suited for urban areas due to its geography-based forwarding and route discovery (RD). In this mode, routes are established that link adjacent junctions with available networks effectively. Using RBVT-P, an unknown destination can be discovered through network-wide flooding. This process is executed by Route Discovery packets, which are equipped with Time-to-Live (TTL) parameters and indicate unique destination addresses

In the Route Reply (RR) phase of the RBVT-R protocol described earlier, the discovered route is placed in the header of an RR packet, of which the destination node is the source. This route, consisting of a range of connected “junctions”, indirectly carries out the route to the final destination from the source. The destination adds the RR header to its present location and directs the packet with the route header over the road sections defined by these junctions. The geographical forwarding approaches enhance node availability to route requests by traversing these junctions. When routing the data, if another route is discovered having less number of junctions, thus indicating a better route, a revised reply is generated [20].

The Proactive protocol (RBVT-P), on the other hand, functions through continuously updating and spreading the structure of a road-based network. This means a proactive mechanism can maintain the appropriate representation of the network connectivity at each node. Each node, using this frequently updated network graph, can then compute the shortest path to every intersection. For information to be sent or received in the case of a proactive network, an RBVT-P uses a location service to determine the exact location of the destination. A thorough description of the working of RBVT-R and RBVT-P affirms that both protocols work differently to manage vehicular networks and enhance the durability of connectivity throughout the network.

4.1 REACTIVE ROUTING PROTOCOL (RBVT-R)

The Reactive Routing Protocol (RBVT-R) is characterized as a dynamic network technique in which routing requests and reply packets are communicated between upper and intermediate nodes, as illustrated in Figure 1. The flow of route request (RREQ) and route reply (RREP) packets is represented by dashed lines, while solid lines denote each established route. Route request packets are initiated by the source node, whereas route reply packets are initiated by the nodes along the route.

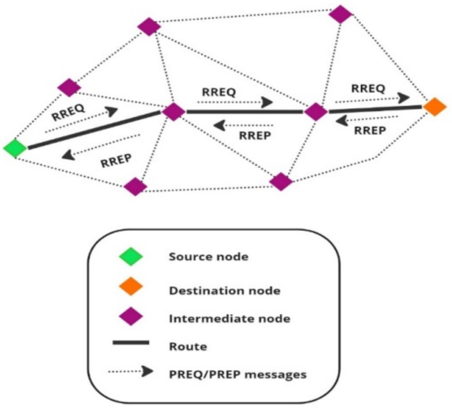


FIGURE 1. **- Reactive Routing Protocol (RBVT-R)**

4.2 PROACTIVE ROUTING PROTOCOL (RBVT-P)

The RBVT-P protocol diagram consists of source, destination, and intermediate nodes, creating an array of nodes as display in Figure (2). These nodes form a type A comprehensive message network, communicating through "UPDATE" messages. Although the model is rigid, it demonstrates that every node is constantly involved in maintaining and updating routes. The most intriguing question is how every node participates proactively and collaboratively in updating routing information to ensure it remains fresh.

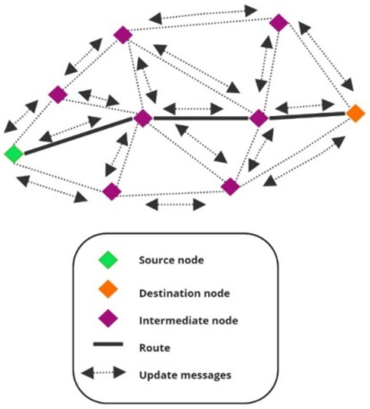


FIGURE 2. **- Proactive Road-Based Routing (RBVT-P)**

5. SNAKE OPTIMIZER ALGORITHM

Optimization issues in the real world are prevalent in various scientific fields, including engineering. A class of algorithms known as Metaheuristic Algorithms (MAs) is modeled after real-world scenarios. These algorithms include physical and chemical methods, evolutionary approaches, swarm intelligence techniques, and human-based methods. These metaheuristics, encompassing physical, evolutionary, and swarm intelligence protocols, are employed to address such issues. Cues from natural colonies are utilized by SI algorithms, while other algorithms are based on populations or individual users.

In Figure (3) our research divides MAs into four distinct types: physical and chemical, evolutionary, swarm intelligence, and human-based. Mathematical programming and metaheuristics are the two primary groups into which these methods fall.

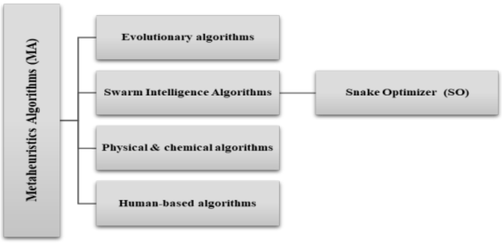


FIGURE 3. **- Classification based on metaheuristics**

Hashim's Snake Optimization Algorithm (SOA) is an innovative optimization method for VANET protocols. It incorporates mathematical simulations of snake activities like eating, fighting, and mating, predicting snake travel based on its current position and distance to food sources. This metaheuristic SOA model enhances VANET protocol routing performance by incorporating snakes' foraging habits and providing versatility and flexibility.

Exploration and exploitation comprise SOA optimization. Unlike other metaheuristic algorithms, SOA separates men and women. Optimization starts with random populations and relies on temperature. Temperature is written mathematically[21]:

$$T = e^{-\frac{t}{T}} \tag{1}$$

where (t) indicates the current iteration, and (T) represents the maximum iterations. The quantity of food (Q) consumed by the snake is given by:

$$Q = 0.5 \times e^{\frac{t-T}{T}} \tag{2}$$

When (Q) values drop below 0.25, the snakes enter an exploration phase, characterized by random food searching. Figure (4) illustrates the flowchart for SOA, depicting the step-by-step process. The food quantity is a critical factor in distinguishing between the exploration and exploitation phases.

This algorithm's unique approach to optimization, leveraging the adaptive behaviors of snakes, demonstrates significant potential in enhancing VANET protocol performance.

5.1 SNAKE MOVEMENT CALCULATION

At the (i) $-$th stage of the optimization process, assume the snake's current position is $(\mathrm{x_i})$ and the target position (food location) is $(\mathrm{x_{target}})$. The snake determines the unit vector for movement direction $((\mathrm{D}))$ based on the distance between its current position and the target position.

$$D = \frac{x_{target} - x_i}{|x_{target} - x_i|} \tag{3}$$

Snake Position Updating:

The snake adjusts its position based on the step size and direction of movement. It's calculated as:

$$x_{i+1} = x_i + step\ size \times direction\ of\ movement \tag{4}$$

Here, (i) represents the current optimization step.

Food Attraction:

To mimic a snake's attraction to food, an attract factor can be added to the movement direction to steer it towards the target location. This is mathematically expressed as:

$$D = \frac{x_{target} - x_i}{|x_{target} - x_i|} + Attract \times (X_{target} - X_i) \tag{5}$$

Dynamic Step Size:c

A dynamic step size technique can prevent the optimization process from getting stuck in local optima too early. This approach gradually reduces the step size during optimization. It is mathematically written as:

$$Step = \frac{Initial\ Step}{1 + i \times step\ decay} \tag{6}$$

Due to the adaptability and flexibility of this algorithm, it is a highly suitable candidate for optimizing VANET protocols regarding routing performance. In this proposed work, the parameters of the routing protocol can be adjusted according to the network characteristics, thereby improving protocol performance while reducing packet delays, overhead, and system overhead.

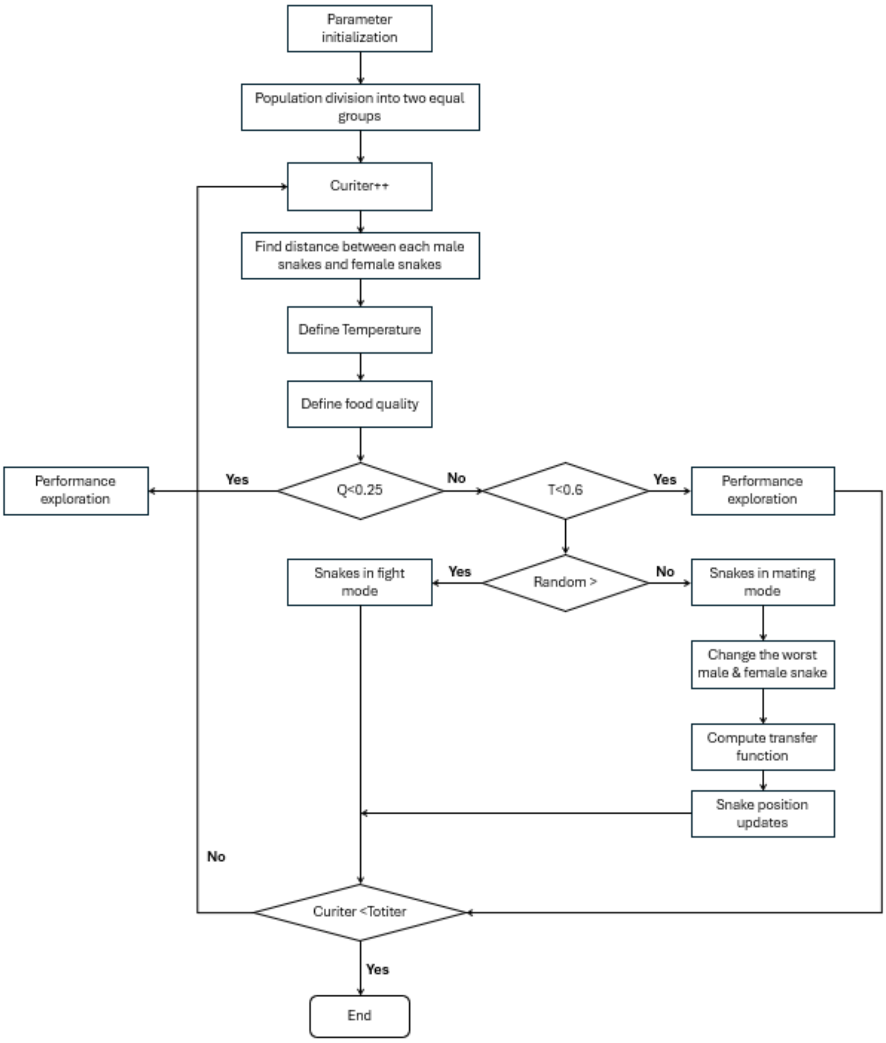


FIGURE 4. - **Flow chart of Snake Optimization Algorithm**

6. SIMULATION TOOLS

6.1 OMNET++ SIMULATOR

The research utilizes OMNeT++ 6.0 as a simulation tool for vehicle network study, renowned for its adaptability and support for network study. The modular simulation framework is crucial for realistic network models, especially in vehicle ad hoc networks (VANETs). The study uses OMNeT++ simulator coupled with SUMO (Simulation of Urban MObility) version 1.19.0, enabling real-time communication between the two systems. This integration is essential for accurate modeling of vehicle communication patterns and motions on city roads.

The simulation setup included the following key configurations:

- City Model: the simulational model of the city of Ernsthausen spans a 400×400 m^2 territory, enabling testing in a more realistic setting of actual physical environment characteristics where the movements of the vehicles and network communication are conducted.
- Signal Transmission: The current experiment establishes the ideal conditions where the signal transmissions over the wireless channel are free of any distortions or physical boundaries, thus achieving a purifying effect for analyzing the performance of the routing protocols in relatively perfect communications environments.
- Frameworks and Tools: along with OMNeT++ and SUMO, the solution was also employing such additional tools as INET-4.5.2 and Veins 5.2. As described by their developers, INET is an open-source package for OMNeT++ focused on the simulation of communication networks scenarios, and Veins complementarily offers a comprehensive suite of opportunities for such vehicular network scenarios by combining OMNeT++ with SUMO.

This system OMNeT++ and its integrations also provide a sophisticate simulation environment that can be used to test and determine how effective the different routing protocols for RBVT-R and RBVT P are rated plays out over different urban traffic scenarios.

6.2 SUMO SIMULATOR

The research utilizes OMNeT++ 6.0 as a simulation tool for vehicle network study, renowned for its adaptability and support for network study. The modular simulation framework is crucial for realistic network models, especially in vehicle ad hoc networks (VANETs). The study uses OMNeT++ simulator coupled with SUMO (Simulation of Urban MObility) version 1.19.0, enabling real-time communication between the two systems. This integration is essential for accurate modeling of vehicle communication patterns and motions on city roads.

Key features and configurations of the SUMO simulator in this study include:

- Urban Road Simulation: SUMO simulates a specific and categorized 400x400 m² urban area of Ernsthausen city, during which the vehicular network protocols are tested in a genuine environment.
- Real-Time Traffic Simulation: The movements and behaviors of the vehicles are simulated in regular urban roads real-time and are essential to reflect the actual prospective under which the network protocols should be examined
- Seamless Integration: SUMO is initialized as the mobility model of the OMNeT++ simulation framework, as activation is achieved through C++ scripts and UTP link. The mobility pattern of vehicles is simulated accurately, linking mobility to network protocol.
- Free Connectivity: the simulated mobile nodes freely connect to each other in the simulated traffic, acting as the perfect platform for the routing protocols' valid testing under dynamic urban traffic conditions.

This setup, integrating SUMO with OMNeT++ and Veins, creates a full simulation environment, ensuring the possibility of close analysis and assessment of distinct routing protocols under a controlled, though genuine urban traffic as Figure (5) illustrates.

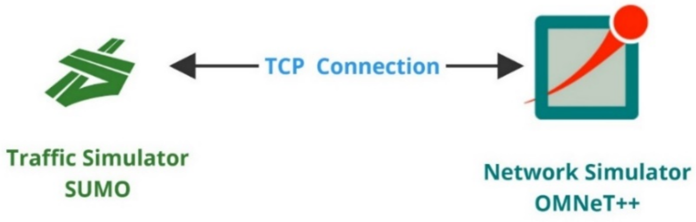


FIGURE 5. - Coupling SUMO and OMNET++

6.3 PARAMETER USED

The aim of the research was to conduct a comparative analysis between the primary versions of RBVT and the counterparts of the fundamental routing classifications:

1. Testing of RBVT-R was carried out by comparing it with other reactive protocols such as AODV (for Ad Hoc networks on demand vector distance), DSR (for discerning MANET protocols), and GPSR (for routing in GPS mode).
2. Assessment of RBVT-P included analysis against state-of-the-art proactive protocols, including the Optimized Link State Routing (OLSR) protocol (a proactive routing protocol for MANETs), the Destination Sequenced Distance Vector (DSDV) protocol (a proactive loop-free distance vector routing protocol), and the Wireless Routing Protocol (WRP) (a table-driven protocol based on link-state algorithms).

The performance evaluation of these protocols was conducted within the context of a Vehicular Ad hoc Network environment, considering the following parameters:

1. Simulation was performed within a 400x400 m² area of Ernsthausen city using real-time integration of OMNET++6.0 and SUMO 1.19.0 on urban roads.
2. The simulation scenario assumed no barriers or signal transmission distortions over the wireless channel during vehicular movement.
3. Veins, employing UTP link and C++ scripts, facilitated SUMO's activation as a mobility model in the OMNeT++ simulation, allowing VANET nodes to seamlessly connect within the simulated traffic environment.
4. Two frameworks, namely INET-4.5.2 and Veins 5.2, were utilized in the simulation process.

5. PC Build Specifications: The system features an Intel® Core™ i9-14900K processor, ASUS PRIME Z790-P motherboard, 4070 Ti 12GB graphics card, 32GB DDR5 memory, 512GB NVME SSD, 1TB SATA SSD, Seasonic 750W PSU, DeepCool 360mm liquid cooler, and a Raptor 290XL case.

Visual representation of the city map used in the simulation is depicted in Figure (6), while Table 1, presents the specific parameters employed in the simulation setup.

Figure 6 . - **The map of the city used in the simulations**.

Table 1. **-Simulation Parameters**

S. No.	Parameter	Value
1	Simulation Area	400×400 m²
2	Simulation Time	100 Seconds
3	Number of Nodes	100 ,250, 350, 650
4	Node Speed	25 mps
5	Transmission Range	250 m
6	Physical Layer	802.11b
7	Transmit Power	1 Mw
8	Routing Protocols	RBVT
9	Hello Interval	1 Second
10	Number of Hello Messages	5

While comparing RBVT-R, it was tested along with general established reactive protocols like AODV, DSR & GPSR and RBVT-P was compared with modern proactive protocols such as OLSR, DSDV and WRP. Measures that were evaluated included average end-to-end delay, packet delivery overhead, path length, and delivery ratio.

7. RESULTS AND DISCUSSION

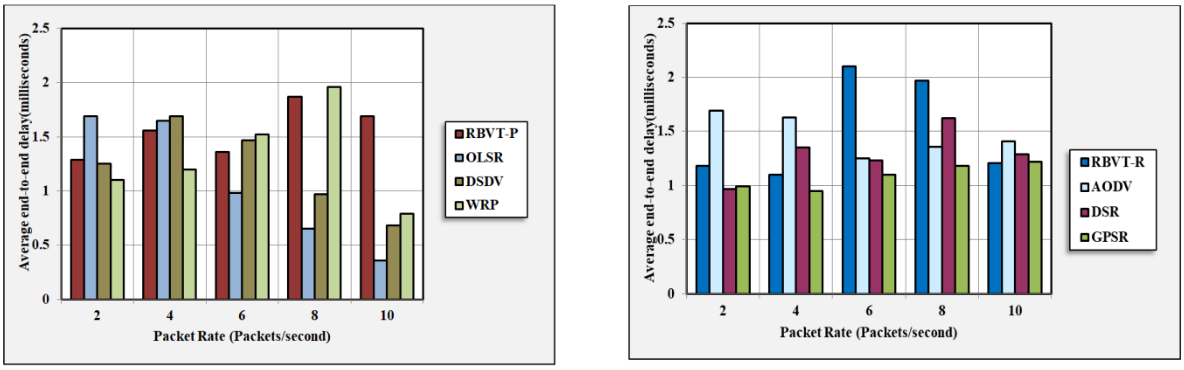
7.1 AVERAGE END-TO-END DELAY RESULTS

7.1.1 BEFORE SNAKE OPTIMIZATION

The time interval between the departure of a packet from its source node to its arrival at the destination node is known as the end-to-end delay. Path reliability, which encompasses both the total number of connections along the route and the stability of these connections, plays a crucial role in determining overall performance. The number of hops in a path, influenced by the number of nodes, is directly related to the probability of successfully establishing a route. This correlation between path stability and the average link duration is logical, as greater stability generally leads to lower end-to-end delays.

Figure (7-a) illustrates the average end-to-end delay experienced by RBVT-P, OLSR, DSDV, and WRP protocols, while Figure (7-b) shows the corresponding delays for RBVT-R, AODV, DSR, and GPSR protocols. Considering a packet rate of 2 packets per second, the end-to-end delays are as follows: RBVT-P 1.29 ms, OLSR 1.69 ms, DSDV 1.25 ms, WRP 1.1 ms, RBVT-R 1.18 ms, AODV 1.69 ms, DSR 0.97 ms, and GPSR 0.99 ms. Similarly, at a packet rate of 10 packets per second, the delays are: RBVT-P 1.69 ms, OLSR 0.36 ms, DSDV 0.68 ms, WRP 0.79 ms, RBVT-R 1.21 ms, AODV 1.41 ms, DSR 1.29 ms, and GPSR 1.22 ms.

The average end-to-end delays, calculated as 1.554 ms for RBVT-P, 1.066 ms for OLSR, 1.212 ms for DSDV, 1.314 ms for WRP, 1.512 ms for RBVT-R, 1.468 ms for AODV, 1.292 ms for DSR, and 1.088 ms for GPSR protocols, revealed certain patterns. Specifically, OLSR demonstrated lower end-to-end delays compared to RBVT-P, while GPSR exhibited reduced delays compared to RBVT-R. Figure (7) shows the computed values concerning the average end-to-end delay.



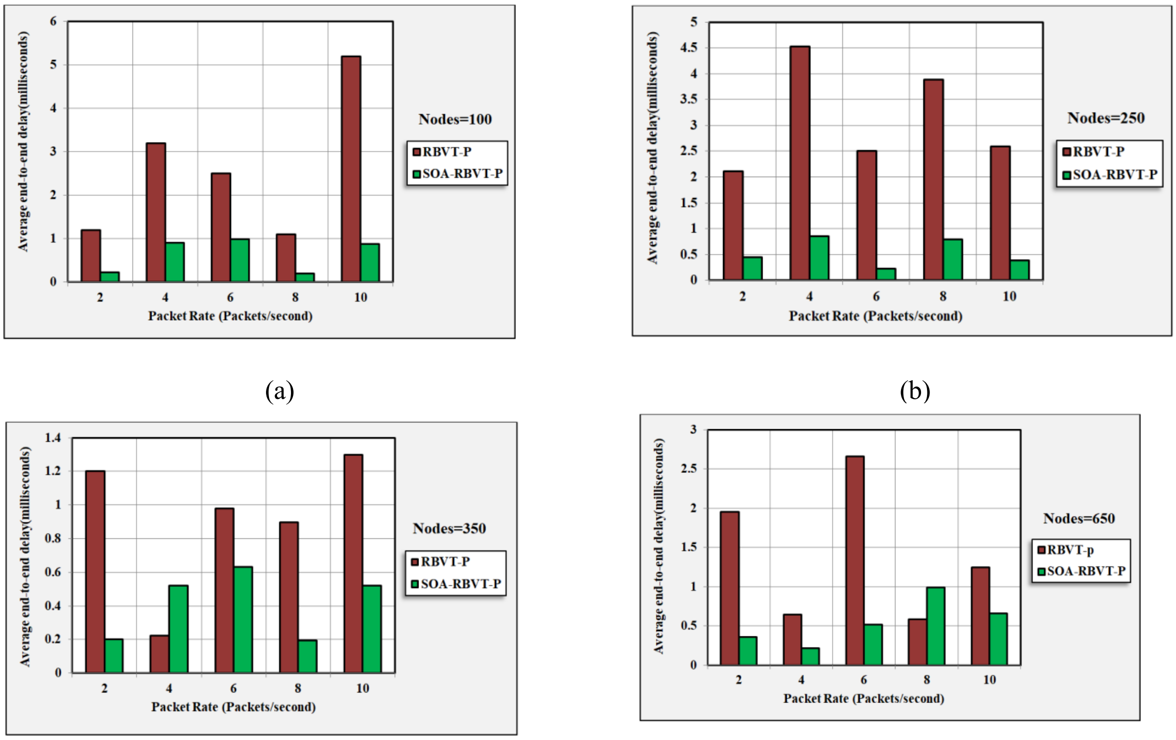
(a) (b)

Figure 7 . - Average end-to-end delay of (a) RBVT-P, OLSR, DSDV, and WRP, and (b) RBVT-R, AODV, DSR, and GPSR protocols

7.1.2 AFTER SNAKE OPTIMIZATION

Figure (8) presents a detailed comparison of average end-to-end delay values for RBVT-P and SOA-RBVT-P protocols across different node configurations: 100 nodes, 250 nodes,350 nodes, and 650 nodes. The RBVT-P protocol exhibits varying delays depending on the number of nodes. For 100 nodes, the average end-to-end delays are 1.1 ms, 1.2 ms, and 5.2 ms for RBVT-P, while for SOA-RBVT-P, they are 0.193 ms, 0.223 ms, and 0.874 ms, respectively. RBVT-P delays of 2.51 ms, 2.59 ms, and 2.11 ms and SOA-RBVT-P delays of 0.22, 0.386, and 0.453 ms persist with 250 nodes. Likewise for RBVT-P delays for 350 nodes and 650 nodes, SOA-RBVT-P has reduced delays, indicating better performance.

The SOA-RBVT-P protocol reduces end-to-end delays, especially as network size increases. The SOA variant reliably reduces latency, improving data transmission efficiency across node densities.



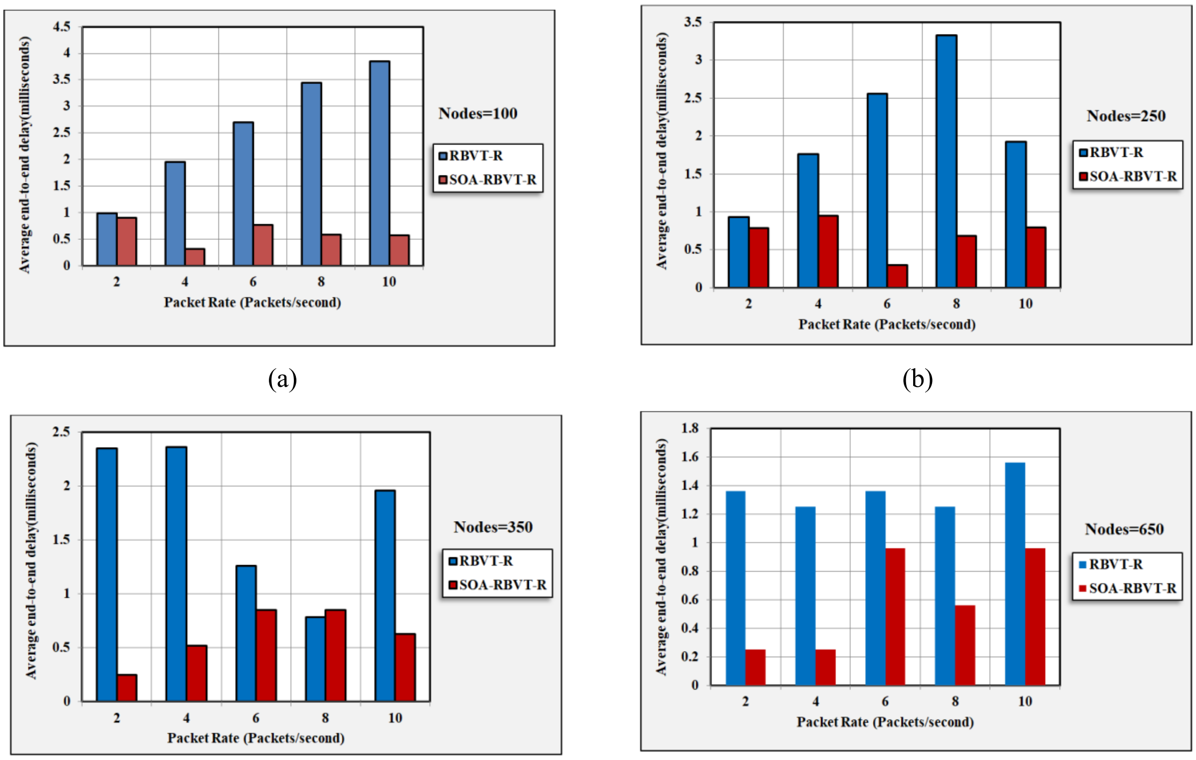
(a) (b)

(c) (d)

FIGURE 8. - Average End-to-End Delay Comparison of RBVT-P and SOA-RBVT-P Protocols over (a) 100, (b) 250 , (c) 350, and (d) 650 Nodes.

Figure (9-a) presents a detailed comparison of average end-to-end delay values for RBVT-R and SOA-RBVT-R protocols across different node configurations: 100 nodes, 250 nodes,350 nodes, and 650 nodes, the RBVT-R protocol delays 100 nodes by 0.981, 1.954, and 2.698 ms, while SOA-RBVT-R delays them by 0.897, 0.31, and 0.764. This trend continues with 250 nodes, showing delays of 0.93 ms, 1.76 ms, and 2.56 ms for RBVT-R and 0.785 ms, 0.945 ms, and 0.295 ms for SOA-RBVT-R. For 350 nodes, the delays are 2.35 ms, 1.258 ms, and 1.96 ms for RBVT-R and 0.25 ms, 0.85 ms, and 0.63 ms for SOA-RBVT-R, likewise in Figure.(8-b). for RBVT-P delays for 350 nodes and 650 nodes, SOA-RBVT-P has reduced delays, indicating better performance.

This comparison highlights the effectiveness of the SOA-RBVT-R protocol in reducing end-to-end delays, especially as the network size increases. The SOA variant consistently achieves lower delays, indicating improved performance and efficiency in data transmission across varying node densities.



(a) (b)

(c) (d)

FIGURE 9. - Average End-to-End Delay Comparison between RBVT-R and SOA-RBVT-R Protocols across different Node Configurations (a) 100, (b) 250 , (c) 350, and (d) 650 Nodes.

This comparison highlights the effectiveness of the SOA-RBVT-R protocol in reducing end-to-end delays, especially as the network size increases. The SOA variant reliably reduces latency, improving data transmission efficiency across node densities.

8. CONCLUSIONS

This work investigates Road-Based Vehicular Traffic (RBVT) routing protocols for VANETs. While RBVT achieves a competitive Average End-to-End Delay (AEED) compared to established protocols at moderate network densities, integrating Snake Optimization Algorithm (SOA) with RBVT (SOA-RBVT) significantly reduced AEED for both proactive (SOA-RBVT-P) and reactive (SOA-RBVT-R) variants, especially in denser networks. For example, at 100 nodes and a low packet rate, SOA-RBVT-P achieved a 64% reduction in AEED compared to RBVT-P, while SOA-RBVT-R also showed a notable improvement. These findings suggest that RBVT offers a competitive baseline, and SOA optimization unlocks substantial performance improvements for both proactive and reactive RBVT approaches in reducing delays within VANETs.

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