Location-Based Routing Protocol with Optimized Data Aggregation for Vehicular Ad Hoc Networks (VANETs)

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Abstract: *Vehicular Ad-hoc Networks (VANETs) are distinct from Mobile Ad-hoc NETworks (MANETs) due to their large-scale node population, potentially reaching millions of vehicles, and their highly dynamic nature. These networks play a vital role in enabling inter-vehicle communication to improve traffic safety and efficiency. Traditional packet-based routing protocols, which rely on direct packet delivery from source to destination, struggle to address the unique challenges of VANETs caused by high vehicle mobility. This paper presents an innovative routing protocol tailored for VANETs, leveraging geographic routing combined with location-aware data aggregation. Simulations conducted using NS-3 and Simulation of Urban MObility (SUMO) reveal that the proposed protocol minimizes message redundancy through aggregation techniques, all while avoiding the complexities of hierarchical structures*.

Keywords: *VANETs, dynamic routing, data efficiency, location-aware communication, mobility optimization*.

Received February 22, 2025; accepted June 16, 2025
https://doi.org/10.34028/iajit/22/5/8

1. Introduction

The rapid advancement of wireless communication technologies has given rise to decentralized architectures centered on Vehicle-to-Vehicle (V2V) communication. This development has introduced a new concept known as Vehicular Ad-hoc Networks (VANETs), which has garnered significant interest in recent years from automobile manufacturers and telecommunication operators.

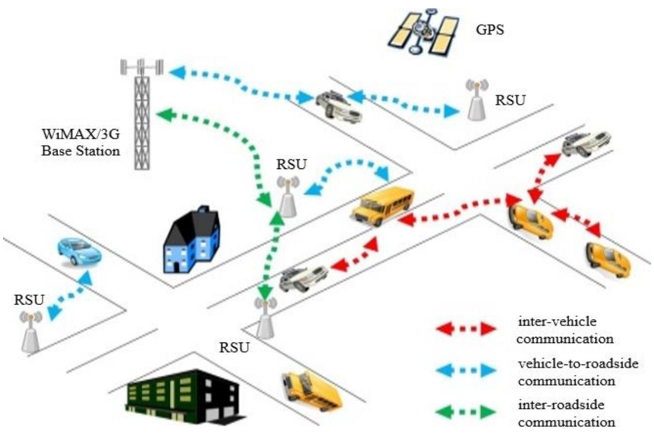

Figure 1. VANET architecture.

VANET, a specialized form of Mobile Ad-hoc NETworks (MANETs), has emerged as a key platform enabling inter-vehicle communication to enhance road traffic safety. A VANET network consists of both static and mobile nodes, enabling various types of communication (Figure 1), including:

- V2V
- Vehicle to Infrastructure (V2I or I2V)
- Infrastructure to Infrastructure (I2I)

The deployment of cost-effective road infrastructure along the roadside, combined with the unlimited energy supply and high speed of vehicles, makes VANET a promising field of research. Communication in VANETs relies on the IEEE 802.11p standard, an extension designed for Wireless Access for Vehicular Environments (WAVE) applications as noted in [10]. This standard supports transmission ranges from 10 to 1000 meters and data rates between 6 Mbps and 27 Mbps. However, in dense environments with multi-hop data transmission, IEEE 802.11p faces challenges such as low transmission rates and high packet loss due to increased packet collisions, as highlighted by Ucar *et al*. [21].

VANET is highly dynamic due to the high speed of vehicles, resulting in rapidly changing network topologies and frequent network fragmentation. Therefore, effective solutions are needed to address these challenges.

Traditional packet-based routing, where packets are forwarded from one node to another without modification from sender to receiver, does not meet the routing requirements of VANET. As stated by Goncalves *et al*. [8], it should be replaced by a new routing paradigm information-centric routing which involves various operations on data, such as dissemination, aggregation, and generation.

This article is structured as follows: Section 2 reviews related work on data aggregation and geographic routing. Section 3 outlines our approach to position-based geographic routing with data aggregation in VANETs. Section 4 presents the evaluation of our proposed protocol, and section 5 concludes the paper while discussing future perspectives.

2. Related Work

Geography-based routing protocols, also known as position-based routing protocols, determine the next hop for packet forwarding based on geographic information. Each vehicle is required to know its own location. Packets are directed to the neighbor closest to the destination without the need to establish or maintain a route between the source and the destination. In the following section, we will discuss several position-based routing protocols.

Moradi-Pari *et al*. [16] introduced Anchor-based Street and Traffic Aware Routing (A-STAR) as a geographic routing protocol designed for urban environments. It utilizes a street map to evaluate road intersections for forwarding packets toward their destination. Additionally, A-STAR leverages city bus route information to identify optimal paths. To address network fragmentation, the protocol includes an algorithm that recalculates a new route whenever fragmentation occurs.

Dhanasekaran *et al*. [4] presented Greedy Perimeter Coordinator Routing (GPCR) as a geographic routing protocol that operates based on two key strategies: limited greedy forwarding and a repair strategy. The source node initiates transmission by directing packets to a node located at an intersection, as intersections are ideal points for making routing decisions. Nodes at these intersections are referred to as coordinators. A source node, V, will forward packets to a coordinator node, A, positioned at an intersection. If no coordinator is available, the node closest to the destination is chosen to continue packet forwarding. In the event of network fragmentation, the protocol either employs the repair strategy or forwards packets along the street until they reach the next coordinator at an intersection. The coordinator then determines the next routing path using the right-hand rule, which involves selecting the street that is counterclockwise to the one from which the packets arrived.

In [5], the Directional Greedy Routing Protocol (DGRP) selects the most suitable relay node based on the positions of neighboring nodes, their speeds, and movement directions. Its routing strategies are similar to those of the Greedy Perimeter Stateless Routing (GPSR) protocol, utilizing both the "greedy forwarding" and "perimeter forwarding" approaches. However, DGRP introduces a location prediction technique that estimates the positions of neighboring nodes during the beacon frame interval, helping to identify the optimal next hop for packet forwarding.

In [23], the Reliable Directional Greedy Routing (RDGR) protocol leverages information about vehicles including their position, direction, and speed to assess the stability of links between neighboring nodes and identify the best relay node. The protocol operates in two phases: the first, called "Reckoning Link Stability (RLS)," evaluates the stability of the routing path, while the second, known as "Potential Score Calculation (PSC)," considers three key factors proximity to the destination, movement direction of nodes, and the reliability of links with neighboring nodes. The node with the highest Potential Score (PS) is selected as the relay, as it has the greatest likelihood of successfully delivering packets to the destination.

In [9], the Grid-based Predictive Geographical Routing (GPGR) protocol divides the geographic area into a two-dimensional logical grid. Each vehicle is required to have a GPS receiver and access to a geographical road map. By determining its current location, a vehicle can identify the specific grid it occupies. Within its grid, a vehicle can transmit data to any vehicle located in one of the eight neighboring grids. When a source Vehicle (Vs) needs to send data to a destination Vehicle (Vd), it selects the vehicle closest to Vd as the relay node, provided that the selected node is within its transmission range.

Feng *et al*. [6] introduced GPSR as a geographic routing protocol. It assumes that each node can determine its position coordinates using a location service, typically through global navigation satellite systems like GPS. GPSR makes greedy forwarding decisions based solely on information from nodes within its communication range. When greedy forwarding is no longer possible, the protocol switches to perimeter forwarding to maintain data transmission.

Each node (or vehicle) gathers information about its neighbors such as node ID, geographic coordinates (x, y), velocity, and more through periodic "Hello" messages. This data is stored in a neighborhood table, enabling nodes to be aware of the real-time positions of their neighbors. In greedy forwarding mode, detailed knowledge of the entire network topology is unnecessary, as routing decisions rely solely on the information in the neighborhood table.

When a node receives a packet, it first checks if it is the intended destination. If so, the packet is delivered locally. If not, the node checks whether the destination is listed in its neighborhood table. If the destination is found, the packet is forwarded directly; otherwise, the packet is routed to the neighbor closest to the destination. In cases where no closer neighbor exists such as in sparse regions the protocol employs the right-hand rule to continue forwarding. The Feng *et al*. [6] highlighted GPSR's scalability as one of its key strengths.

Geographic Source Routing (GSR) [3] is a geographic routing protocol designed for urban environments. It relies on a city's geographic map to function effectively. To determine the current positions of neighboring nodes, the source node broadcasts a position request packet. Upon receiving this request, neighboring nodes respond with their location information. Using these responses, the source node calculates the shortest path to the destination by applying Dijkstra's algorithm.

The performance of GSR is evaluated based on several key parameters:

- Packet delivery rate: measures the success rate of packet delivery relative to the distance between the source and destination.
- Bandwidth consumption: assesses the average bandwidth usage per second concerning the distance.
- Latency: evaluates the delay experienced by the first packet in each connection relative to the distance.
- Hop count: calculates the average number of hops required to reach the destination based on the distance.

In Wireless Sensor Networks (WSNs), data aggregation plays a crucial role in ensuring low transmission latency and energy efficiency. This process involves various techniques that combine information from multiple sources to produce organized and concise data. Hung and Peng [11], Testa *et al*. [20], and Usman *et al*. [22] proposed several aggregation methods, where aggregator nodes are structured in a hierarchical tree format. However, as noted in [8], these methods are not well-suited for VANETs due to the high mobility and speed of vehicles.

Tiny AGgregation (TAG) [20] is a protocol designed for data aggregation and routing in WSNs. It utilizes tree structures to manage both aggregation and data routing. TAG performs aggregation by processing data as it is received from sensor nodes, filtering out irrelevant information, and combining relevant data into more concise records when possible. Before data can be requested from all sensor nodes and routed back to the requester, a routing tree must be established. To create this tree, the root node (the node initiating the request) broadcasts a message containing its unique identifier.

Karp and Kung [13] proposed hierarchical aggregation as a scalable and fault-tolerant approach to address the challenges of efficient computation and accurate data aggregation in MANETs. Karp and Kung [13] highlight that neither distributed nor centralized methods alone can effectively solve scalability issues when dealing with a large number of nodes.

In fully distributed systems, where each node exchanges data with all others, the complexity is $O(N^2)$ for N nodes, which becomes impractical as N increases. On the other hand, centralized approaches, where all nodes send their data to a single leader node, can overwhelm the wireless link due to limited bandwidth, leading to data loss or link failures.

To overcome these limitations, Karp and Kung [13] introduces the GridBox hierarchy-based method. This approach divides the total number of nodes, M, into M/H grids, with each grid containing H nodes. Here, H is a constant integer, chosen independently of M, and known to all nodes in the network. The aggregation process occurs hierarchically from the bottom to the top in $Log_k(N)$ phases. In the first phase, a node M_j exchanges its data, along with any data it has collected from other nodes, with the nodes within its own grid.

In [14, 15], aggregation with the greedy incremental tree is introduced as a data aggregation method based on directed broadcast. Directed broadcast is an attribute-based communication technique commonly used in application-oriented WSNs, where data is represented as key-value pairs. When a sender node wants to transmit data, nearby nodes that are interested (referred to as sinks) respond by sending messages back to the source, indicating their interest in the data.

Upon receiving these responses, the source node starts collecting data from the sinks. In cases where multiple nodes respond, data may be aggregated within the network. To optimize this process and reduce communication costs, the author suggests relaying data through a newly formed greedy incremental tree rooted at the sender, rather than using the traditional return paths from the sinks.

3. Location-Based Routing and Data Aggregation

As illustrated in Figure 2, in road traffic condition detection applications (such as congestion monitoring, rain detection, roadworks, etc.,), vehicles within the same area often generate identical traffic reports, leading to unnecessary bandwidth usage. To address this, our goal is twofold: first, to reduce information redundancy by aggregating similar traffic reports generated by different vehicles, and second, to ensure efficient routing in the highly dynamic vehicular environment, as depicted in Figure 3.

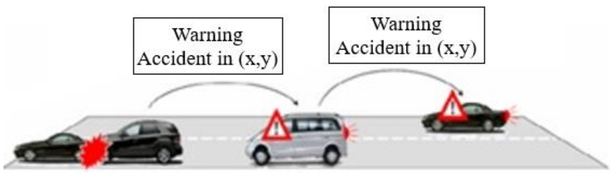

Figure 2. Identification and creation of traffic condition reports.

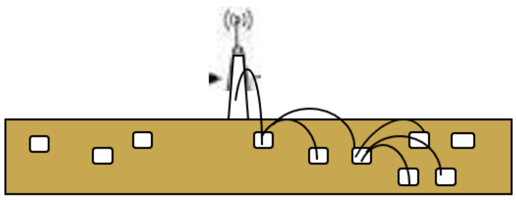

Figure 3. Combining messages generated by vehicles.

In our proposed protocol (Figure 4), it is assumed that each vehicle is equipped with a GPS receiver and can communicate with other vehicles using wireless communication devices. Data packets are transmitted through short-range wireless technologies such as IEEE 802.11p [2] and Dedicated Short Range Communication (DSRC) [12]. Road Side Units (RSUs) are positioned along the roadside to collect road condition reports from vehicles and forward this information to traffic management servers.

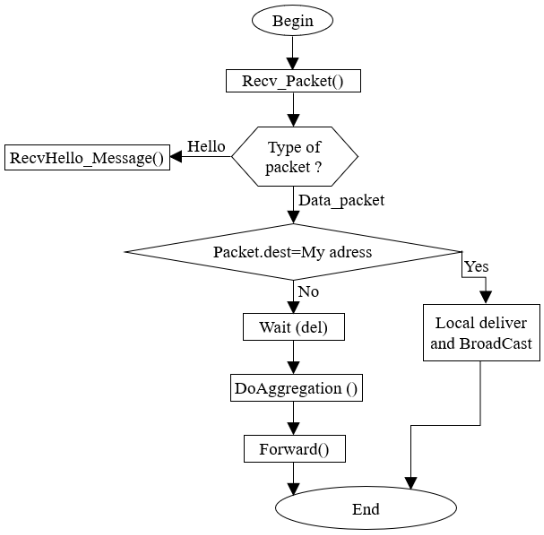

Figure 4. Geographic routing protocol with data aggregation.

When vehicles in a specific area detect events (e.g., accidents, roadworks, rain), they begin sending traffic status updates to the nearest RSU. To optimize data transmission, each intermediate vehicle introduces a brief waiting period to allow for the aggregation of similar reports (Figure 3). After this aggregation phase, the protocol uses the same routing strategy as the GPSR protocol [6], employing greedy forwarding if a neighboring vehicle is closer to the RSU. If no such vehicle is within range, the protocol switches to perimeter forwarding mode.

The aggregation delay can be determined in two ways:

a) By waiting for a period equal to the transmission delay of the packet that triggered the aggregation from the previous hop.
b) By selecting a random delay.

Each node (vehicle) gathers information about its neighboring nodes such as node ID, geographic coordinates (x, y), speed, and more through the regular exchange of “Hello” messages. This data is stored in a neighborhood table for efficient reference.

4. Performance Assessmentx

To evaluate our approach, we selected the Network Simulator 3 (NS3) [17] and used Simulation of Urban MObility (SUMO) [19] for modeling vehicle mobility. NS3, the successor to NS2, has been shown to outperform NS2 in terms of Central Processing Unit (CPU) efficiency and memory usage, as noted by Gama *et al*. [7]. NS3 is an open-source, flexible network simulation platform that supports both C++ and Python programming languages. Licensed under GNU GPLv2, it is widely used for research and development purposes. NS3 supports various Open Systems Interconnection (OSI) layer protocols, including WiFi, across the application, transport, network, and Medium Access Control/Physical Layer (MAC/PHY) layers. It also benefits from strong community support, with active contributions from users and developers worldwide.

SUMO is an open-source, microscopic road traffic simulator designed for handling large-scale road networks. It is portable and capable of simulating detailed traffic scenarios. Key features include collision-free vehicle movement, support for various vehicle types, and multi-lane roads with lane-changing capabilities. Mobility trace models in SUMO can be created in two ways:

1. By importing data from existing sources like OpenStreetMap [18] of different formats using the “netconvert” tool.
2. By generating custom mobility scenarios based on user requirements with the “netgenerate” application.

4.1. NS3-Based Implementation

In NS3, routing is implemented using specific objects. The Ipv4L3Protocol simulates the network layer (layer 3) and relies on the Ipv4RoutingProtocol object during simulation setup. This abstract class provides interfaces for two key methods: RouteInput, which is triggered when a packet is received and can invoke the forwarding method, and RouteOutput, which is called when sending a packet. In our implementation, Figures 5, 6, and 7 illustrate the diagrams for the three methods: RouteInput(), Forwarding(), and RouteOutput() respectively.

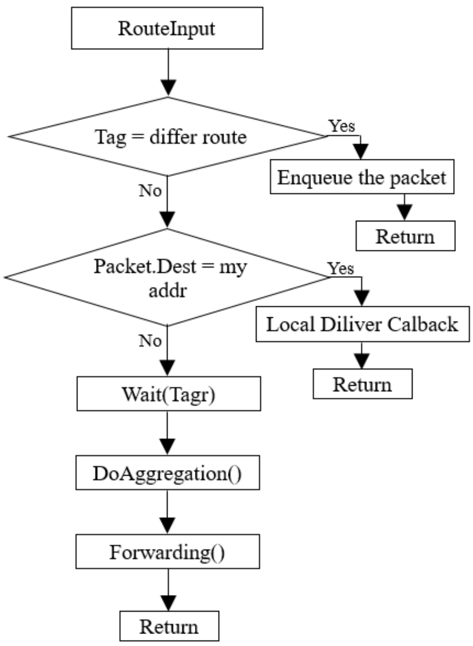

Figure 5. NS-3 route-input method.

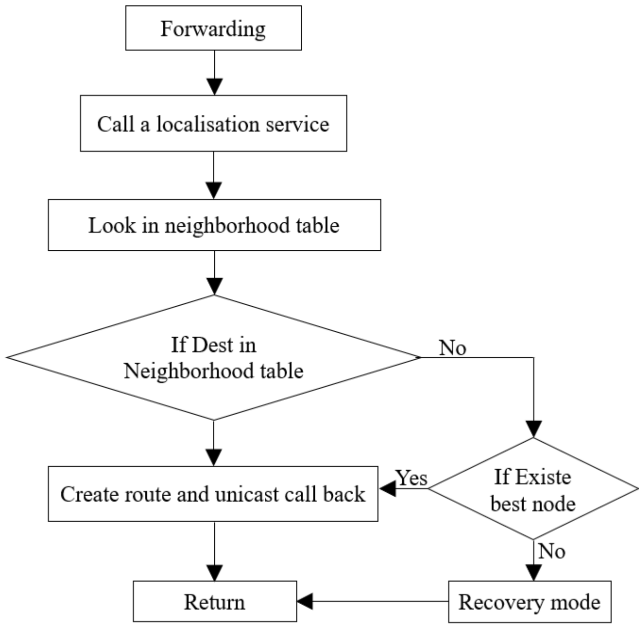

Figure 6. NS-3 forwarding method.

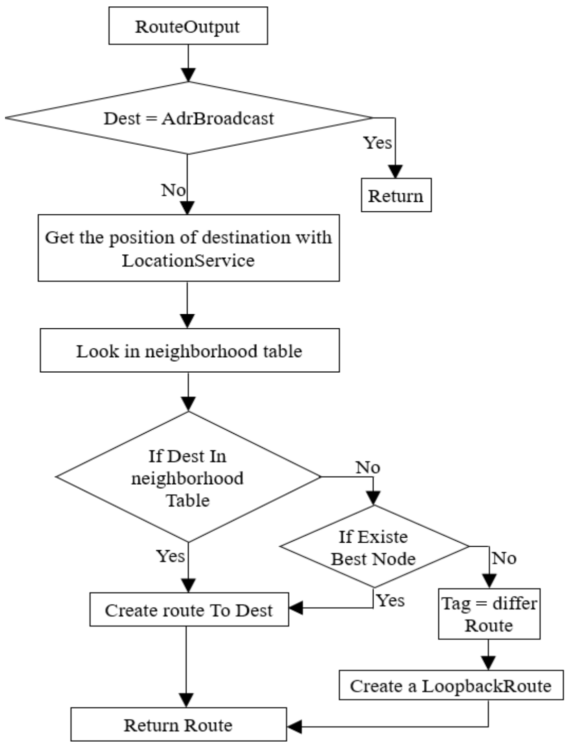

Figure 7. NS-3 route-output method.

4.2. Testing Phase

We simulated a mobility scenario involving 119 vehicles, with 10 of them generating 64-byte road traffic reports at a rate of 1024 kbps within a highway area measuring 4.6 km by 3.0 km. A fixed roadside station was deployed to receive these reports (packets) and forward them to a server for processing and traffic management. For signal propagation, we applied the ITU R-1411 propagation loss model, as recommended by ITU [12], which is well-suited for VANET environments. To evaluate our approach under different conditions, we conducted a series of tests. We began by comparing two scenarios: one where packets are transmitted without aggregation and another where aggregation is applied, keeping the transmission range fixed at 300 m. Next, we varied the transmission range from 200 m to 400 m to observe its impact on our approach when the aggregation delay is calculated. Additionally, we analyzed the performance of our protocol with and without the Request to Send (RTS) and Clear to Send (CTS) mechanisms enabled, using a fixed transmission range of 250 m. The RTS/CTS mechanism helps address hidden and exposed node issues [1]. Finally, we compared our protocol's performance with AODV, a reactive routing protocol, and OLSR, a proactive routing protocol.

4.3. Evaluation Parameters

We employed the following metrics to evaluate the performance of our approach:

1. Average delay: the total end-to-end delay divided by the number of received packets.
2. Average jitter: the sum of jitter values divided by the total number of received packets.
3. Average packet loss ratio: the ratio of lost packets to the sum of received and lost packets.
4. Average routing throughput (Kbps): calculated by multiplying the total bytes received at the destination by 8.0, then dividing by the simulation time (in seconds) and scaling to Kbps.

4.4. Interpretation of Results

The results in Table 1 indicate that using aggregation (Random Waiting and calculated waiting) outperforms in all evaluated metrics, while the non-aggregation strategy shows the least favorable performance as follows:

1. Delay: without aggregation shows the highest delay (100.7 ms), indicating congestion or inefficient packet handling. Aggregation with calculated waiting yields the lowest delay (56.3 ms), likely due to better timing control before forwarding packets.
2. Jitter (variation in delay): without aggregation suffers from very high jitter (98.6 ms), which is problematic for real-time applications. Calculated waiting shows improved stability with only 58.1 ms, suggesting more predictable delivery.
3. Packet loss ratio: extremely high packet loss without aggregation (98%) points to a heavily overloaded or unreliable network. Aggregation dramatically improves reliability, especially with calculated waiting (58% loss), although this is still a significant amount of loss.
4. Routing throughput: calculated waiting shows the highest throughput (0.42 Kbps), suggesting it maintains a better balance of packet success and network efficiency. Random waiting slightly reduces throughput (0.34 Kbps), possibly due to less optimal scheduling.

Table 1. Data transmission without aggregation vs. with aggregation (random and calculated waiting).

	Mean delay (ms)	**Mean jitter (ms)**	**Mean Pkt loss ratio**	**Mean routing throughput (Kbps)**
without aggregation	100.7	98.6	98 %	0.37
with aggregation-random waiting	62.6	64.6	65 %	0.34
with aggregation calculated waiting	56.3	58.1	58 %	0.42

Table 2. Comparison of performance with RTS/CTS mechanism enabled and disabled.

	Mean delay (ms)	**Mean jitter (ms)**	**Mean Pkt loss ratio**	**Mean routing throughput (Kbps)**
RTS/CTS enabled	65.7	64.8	%58	0.31
RTS/CTS disabled	52.9	57.3	%56	0.30

Table 2 indicates that performance is better when the RTS and CTS mechanism is disabled compared to when it is enabled as follows:

1. Mean delay: without aggregation: highest delay (100.7 ms), suggesting network congestion and inefficiencies. With Random Waiting: Delay drops significantly to 62.6 ms. With Calculated Waiting: Lowest delay (56.3 ms), indicating more controlled and optimized data handling.
2. Mean jitter: without aggregation: extremely high jitter (98.6 ms) bad for real-time applications. With Random Waiting: Jitter decreases to 64.6 ms. With calculated waiting: best stability (58.1 ms), offering smoother data flow.
3. Packet loss ratio: without aggregation: extremely poor performance with 98% packet loss. With random waiting: noticeable improvement to 65% loss. With Calculated Waiting: Further improved to 58%, although still high, showing aggregation helps reduce loss but optimization is still needed.
4. Routing throughput: without aggregation: moderate throughput (0.37 Kbps). With random waiting: Slight drop to 0.34 Kbps, likely due to delayed forwarding. With calculated waiting: best performance at 0.42 Kbps, likely from better-timed transmissions reducing retransmissions and losses.

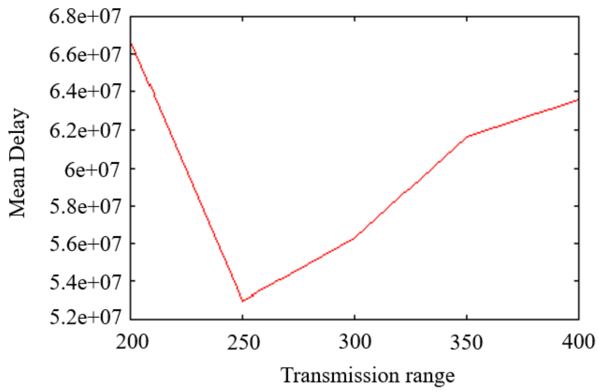

Figure 8. Average delay variation based on transmission range (with calculated aggregation delay).

Figure 8 illustrates that the optimal delay is achieved within the 250 m to 300 m range increasing the transmission range beyond that reduces the number of hops but introduces other delays, such as more retransmissions due to fading or increased contention. Conversely, a smaller range leads to many hops, increasing cumulative delay.

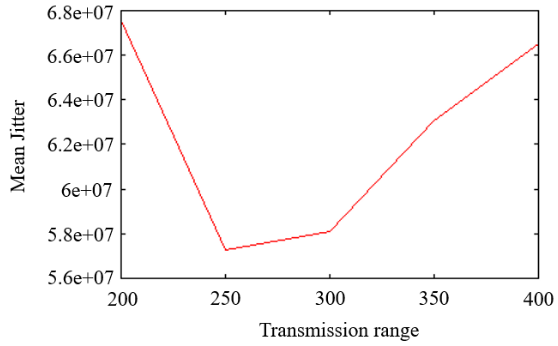

Figure 9. Average jitter variation based on transmission range (with calculated aggregation delay).

Similarly, Figure 9 demonstrates that jitter performance also improves within this range. Our protocol shows better responsiveness between 250 m and 300 m compared to other transmission ranges, Suggests the network is most stable at this range less variability in packet delivery times and likely more consistent link quality. At 200 m range highest jitter indicates unpredictable transmission delays, likely due to multiple short-range hops and increased contention. From 250 to 400 Jitter rises again, peaking at 400. This could be due to increased retransmissions, fading, or signal degradation over longer distances, resulting in less predictable latency.

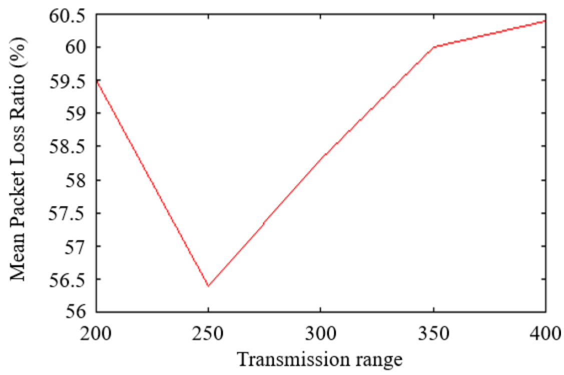

Figure 10. Average packet loss variation based on transmission range (with calculated aggregation delay).

Figure 10 illustrates that the packet loss rate is lowest at a transmission range of 250 m, with similarly favorable results observed between 250 m and 300 m, suggests an optimal transmission range, where link reliability is maximized and node-to-node communication is efficient. At 200 m range high packet loss, likely due to frequent short-range transmissions, resulting in congestion, buffer overflows, or increased collisions. From 250m to 400m steady increase in packet loss, peak at 400 range. This may result from longer links being less reliable, causing more packet errors and retransmissions especially if signal strength weakens with distance.

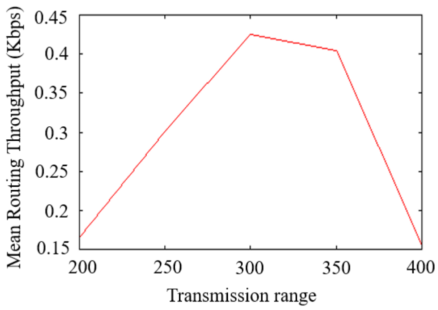

Figure 11. Average throughput variation based on transmission range (with calculated aggregation delay).

Figure 11 indicates that routing throughput reaches its peak between 300 m and 350 m. to short a range might limit connectivity and thus reduce the overall throughput. Increasing the transmission range too much might lead to increased interference between more distant vehicles and potentially higher contention for the communication medium. This could explain the drop in throughput beyond the optimal range. More vehicles within the transmission range mean more potential communication attempts, which can lead to collisions and retransmissions, ultimately reducing the effective throughput per vehicle. A higher density might benefit from a shorter transmission range to reduce interference, while a lower density might require a larger range to maintain connectivity.

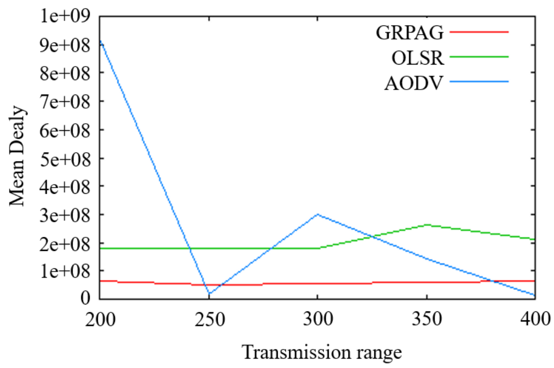

Figure 12. Average delay comparison with AODV and OLSR protocols.

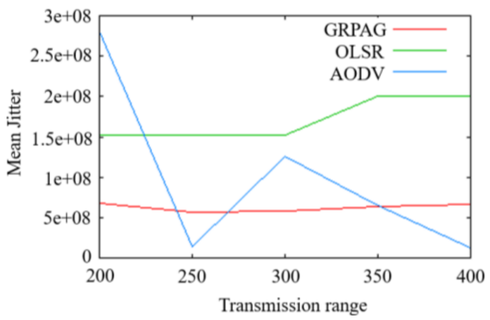

Figure 13. Average jitter comparison with AODV and OLSR protocols.

Figures 12 and 13 illustrate that our approach Geographic Routing Protocol with AGgregation (GRPAG) maintains greater stability compared to Optimized Link State Routing (OLSR) and Ad-hoc On-Demand Distance Vector (AODV), achieving lower average delay and jitter. In Figure 12 GRPAG consistently achieves the lowest mean delay across all transmission ranges. This suggests that the underlying principles of this routing protocol (location based and data aggregation) make it very efficient in forwarding packets with minimal delay, regardless of the transmission range within this tested scope. In Figure 13 GRPAG consistently exhibits the lowest and most stable mean jitter. This suggests that its routing mechanism provides very predictable and consistent packet delivery times, which is crucial for real-time applications.

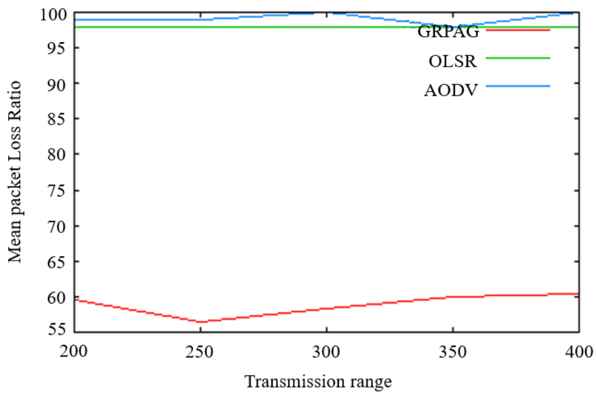

Figure 14. Performance comparison with AODV and OLSR-average packet loss ratio.

Figure 14 illustrates that our approach outperforms OLSR and AODV, achieving a lower average packet loss ratio. GRPAG shows a significantly lower packet loss ratio compared to AODV and OLSR. GRPAG manages to deliver a considerably larger portion of the transmitted packets.

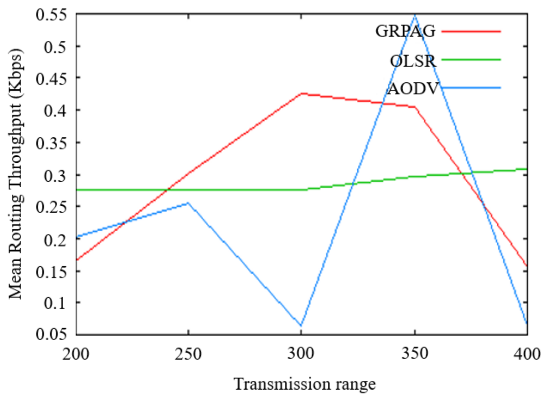

Figure 15. Performance comparison with AODV and OLSR-average throughput.

Figure 15 demonstrates that our approach achieves higher mean routing throughput compared to OLSR and AODV. GRPAG generally provides a higher mean routing throughput than OLSR and AODV across a significant portion of the tested transmission ranges (especially around 300m-350m). It demonstrates a more consistent upward trend before decreasing at the highest range. GRPAG appears to be a good choice, offering a generally higher throughput than OLSR and a more stable high throughput compared to AODV.

5. Conclusions

In this study, we introduced a routing approach for VANETs that combines geographic routing with the aggregation of road traffic reports. By aggregating traffic data, our method effectively reduces network congestion caused by redundant information, while geographic routing eliminates the need for maintaining complex routing tables. Simulations conducted using NS3 and SUMO demonstrated strong performance across various evaluation metrics. For future work, we plan to explore the integration of 5G cellular technology to enhance connectivity within VANET environments.

References

[1] Abu Salem A., "An Effective Management Model for Data Caching in MANET Environment," *The International Arab Journal of Information Technology*, vol. 20, no. 6, pp. 841-851, 2023. https://doi.org/10.34028/iajit/20/6/1

[2] Armstrong L., Dedicated Short Range Communications Project, http://www.leearmstrong.com/DSRC/DSRCHomeset.htm, Last Visited, 2025.

[3] Chen C., Liu L., Qiu T., Wu D., and Ren Z., "Delay-Aware Grid-Based Geographic Routing in Urban VANETs: A Backbone Approach," *IEEE/ACM Transactions on Networking*, vol. 27, no. 6, pp. 2324-2337, 2019. DOI: 10.1109/TNET.2019.2944595

[4] Dhanasekaran S., Ramalingam S., Baskaran K., and Vivek Karthick P., "Efficient Distance and Connectivity Based Traffic Density Stable Routing Protocol for Vehicular Ad Hoc Networks," *IETE Journal of Research*, vol. 70, no. 2, pp. 1150-1166, 2023. https://doi.org/10.1080/03772063.2023.2252385

[5] Ding Z., Ren P., and Du Q., "Mobility Based Routing Protocol with MAC Collision Improvement in Vehicular Ad Hoc Networks," *in Proceedings of the IEEE International Conference on Communications Workshops*, Kansas, pp. 1-6, 2018. https://ieeexplore.ieee.org/document/8403517

[6] Feng C., Zhang Y., Demirkol I., and Heinzelman W., "Stateless Multicast Protocol for Ad Hoc Networks," *IEEE Transactions on Mobile Computing*, vol. 11, no. 2, pp. 240-253, 2011. https://doi.org/10.1109/TMC.2011.61

[7] Gama O., Santos A., Costa A., Dias B., and et al., "Evaluation of Broadcast Storm Mitigation Techniques on Vehicular Networks Enabled by WAVE or NDN," *in Proceedings of the 3rd EAI International Conference on Intelligent Transport Systems, from Research and Development to the Market Uptake*, Braga, pp. 219-236, 2019. https://link.springer.com/chapter/10.1007/978-3-030-38822-5_15

[8] Goncalves F., Franca F., and Amorim C., "RAdNet-VE: An Interest-Centric Mobile Ad Hoc Network for Vehicular Environments," *arXiv Preprint*, vol. arXiv:1604.00589v10, pp. 1-24, 2017. https://doi.org/10.48550/arXiv.1604.00589

[9] Gurumoorthi E. and Ayyasamy A., "Performance Analysis of Geocast Based Location Aided Routing Using Cache Agent in VANET," *International Journal of Information Technology*, vol. 14, no. 1, pp. 125-134, 2022. https://link.springer.com/article/10.1007/s41870-019-00410-x

[10] Hozouri A., Mirzaei A., RazaghZadeh S., and Yousefi D., "An Overview of VANET Vehicular Networks," *arXiv Preprint*, vol. arXiv:2309.06555v1, pp. 1-20, 2023. https://doi.org/10.48550/arXiv.2309.06555

[11] Hung C. and Peng W., "Optimizing In-Network Aggregate Queries in Wireless Sensor Networks for Energy Saving," *Data and Knowledge Engineering*, vol. 70, no. 7, pp. 617-641, 2011. https://doi.org/10.1016/j.datak.2011.03.008

[12] International Telecommunication Union, Radiocommunication Sector of ITU, https://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.2160-0-202311-I!!PDF-E.pdf, Last Visited, 2025.

[13] Karp B. and Kung H., "GPSR: Greedy Perimeter Stateless Routing for Wireless Networks," *in Proceedings of the 6th Annual International Conference on Mobile Computing and Networking*, Boston, pp. 243-254, 2000. https://dl.acm.org/doi/10.1145/345910.345953

[14] Ko Y. and Vaidya N., "Geocasting in Mobile Ad Hoc Networks: Location-based Multicast Algorithms," *in Proceedings of the 2nd IEEE Workshop on Mobile Computing Systems and Applications*, New Orleans, pp. 101-110, 1999. https://ieeexplore.ieee.org/document/749282

[15] Ko Y. and Vaidya N., "GeoTORA: A Protocol for Geocasting in Mobile Ad Hoc Networks," *in Proceedings of the International Conference on Network Protocols*, Osaka, pp. 240-250, 2000. https://ieeexplore.ieee.org/document/896308

[16] Moradi-Pari E., Tian D., Bahramgiri M., Rajab S., and Bai S., "DSRC Versus LTE-V2X: Empirical Performance Analysis of Direct Vehicular Communication Technologies," *IEEE Transactions on Intelligent Transportation Systems*, vol. 24, no. 5, pp. 4889-4903, 2023. DOI: 10.1109/TITS.2023.3247339

[17] NS-3, Network Simulator (Documentation),

http://www.nsnam.org, Last Visited, 2025.

[18] OpenStreetMap, http://www.openstreetmap.org, Last Visited, 2025.

[19] SUMO, Simulation of Urban Mobility, http://sumo.sourceforge.net, Last Visited, 2025.

[20] Testa L., Audrito G., Damiani F., and Torta G., "Aggregate Processes as Distributed Adaptive Services for the Industrial Internet of Things," *Pervasive and Mobile Computing*, vol. 85, pp. 101658, 2022. https://doi.org/10.1016/j.pmcj.2022.101658

[21] Ucar S., Ergen S., and Ozkasap O., "VeSCA: Vehicular Stable Cluster-based Data Aggregation," *in Proceedings of the International Conference on Connected Vehicles and Expo*, Vienna, pp. 1080-1085, 2014. DOI: 10.1109/ICCVE.2014.7297517

[22] Usman M., Gebremariam A., Raza U., and Granelli F., "A Software-Defined Device-to-Device Communication Architecture for Public Safety Applications in 5G Networks," *IEEE Access*, vol. 3, pp. 1649-1654, 2015. DOI: 10.1109/ACCESS.2015.2479855

[23] Zheng X., Zhang M., Chen C., Nguyen Q., Zhu X., and Pan S., "Structure-Free Graph Condensation: From Large-Scale Graphs to Condensed Graph-Free Data," *in Proceedings of the 37th International Conference on Neural Information Processing Systems*, New Orleans, pp. 6026-6047, 2023. https://dl.acm.org/doi/10.5555/3666122.3666386

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