Navigating Exposed Node Challenges in Vehicular Ad-Hoc Networks through Variable Transmission Ranges

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Abstract. Vehicular Adhoc Network (VANET) is a network that uses the wireless medium to establish communication between moving vehicles and other network devices. Since VANETs deal with highly mobile vehicles at random speeds, this leads to a dynamic network topology. Due to the dynamic nature of the VANETs, each node tends to enter and leave the surrounding node's transmission range, thus constantly exposing itself. This exposure can lead to consequences such as increased collision and unnecessary waiting times, thus leading to reduced throughput and reliability. This paper proposes a dynamic calculation of network density using existing infrastructure. This approach dynamically adjusts the transmission range based on the vehicle density. Simulations show the relationship between the degree of the node being exposed and the dynamic transmission range.

Keywords: VANET · Exposed Node · Vehicle Density.

1 Introduction

Vehicular Ad-hoc Networks (VANETs) are a type of mobile network that allows vehicles to communicate with each other through wireless medium [1]. The characteristics of a vehicular ad hoc network are unique compared to other mobile ad hoc networks [2]. The differentiating properties of VANETs provide us with opportunities to enhance network performance. However, at the same time, they present unique challenges. A VANET is fundamentally different from Mobile Ad-hoc Networks (MANETs) [3] in terms of,

- High Mobility: The nodes in VANETs usually move at high speeds, which makes it harder to predict a node's position [4].
- Rapidly varying network topology: Due to high node mobility and variable speed of vehicles, the position of the node changes frequently. Thus, network topology in VANETs tends to change more frequently [5].
- Unbounded network size: VANET scope can be one city, several cities, or countries, which implies that the network size in VANETs is geographically unbounded [6].
- Frequent exchange of information: The ad-hoc nature of VANETs encourages the nodes to collect information from the other vehicles. Hence, the exchange of information among nodes becomes frequent [7].

VANETs are booming at an increasing pace due to their ability to broadly impact the road infrastructure, offering security, emergency warnings, traffic stats, and much more [1, 8]. One critical

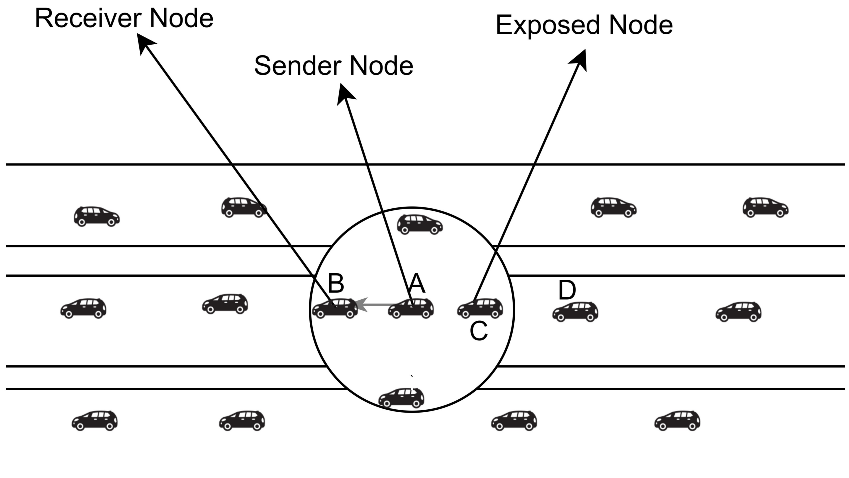

Fig. 1: Exposed Node Problem In VANETs

challenge in implementing VANETs is the "Exposed node problem" [9]. A node becomes an exposed node when it cannot transmit or receive data from other nodes due to being within the transmission range of two or more communicating nodes [10]. This can occur when two nodes are too close together or obstacles block the signal. Vehicle 'A' communicates with vehicle 'B' in the scenario depicted in Fig. 1. Let 'C' represent any vehicle within the transmission range of 'A' that seeks to communicate with vehicle 'D', which is not within 'A's transmission range. However, because 'C' is exposed to the transmission of vehicle 'A', it mistakenly perceives the channel as busy and unnecessarily delays communication with 'D'. In VANETs, the dynamic topology further exacerbates this issue [11].

Exposed nodes in VANETs can lead to a lot of consequences, which include,

– Reduced network throughput: When nodes are exposed, they cannot communicate with each other effectively, which can reduce the overall throughput of the network [12, 13].
– Increased packet collisions: Exposed nodes can also increase packet collisions as nodes try to transmit simultaneously and interfere.
– Reduced network reliability: The combination of reduced throughput, increased collisions, and increased packet loss can all lead to a reduction in the overall reliability of the network [14].
– The Exposed Node Problem leads to degraded communication reliability as nodes experiencing interference fail to transmit data, resulting in packet loss, delays, or complete message failures. The rapid movement of vehicles exacerbates this issue, increasing the likelihood of occurrences of the Exposed Node Problem and subsequent communication disruptions [13].

This paper proposes a method wherein each node varies its transmission range according to the vehicle density and depicts how this method reduces the exposed node problem. This paper also discusses some of the approaches that have already been proposed to solve the exposed node problem. The objectives of the proposed solution include: First, to build an efficient solution to increase the throughput of the VANETs. Second, to consider the dynamic nature of VANETs, where dynamically manipulating transmission power is used to counter the changing network connections [2].

The rest of the paper is arranged as follows: Section 2 handles the related work on exposed nodes, Section 3 elaborates on the proposed solution, and Section 4 discusses the result and analysis. Finally, Section 5 concludes the paper while also featuring the future scope of this paper.

2 Literature Work

This section of the paper presents a review of previous solutions proposed to reduce the exposed node problem in VANETs. Subsection 2.1 explains the CMAP (Conflict Maps) approach, which deduces the exposed node and excludes a collided transmission by consulting an existing reactive channel access protocol called "Conflict Map". Subsection 2.2 explains the RTS/CTS Validation method, which checks if the initiated communication between the nodes exists or not [15]. Subsection 2.3 makes use of an adaptive range based on the free-flow parameter [2]. Subsection 2.4 elaborates on the use of asymmetric transmission ranges for CTS and RTS messages to other nodes [16].

2.1 Conflict Map (CMAP)

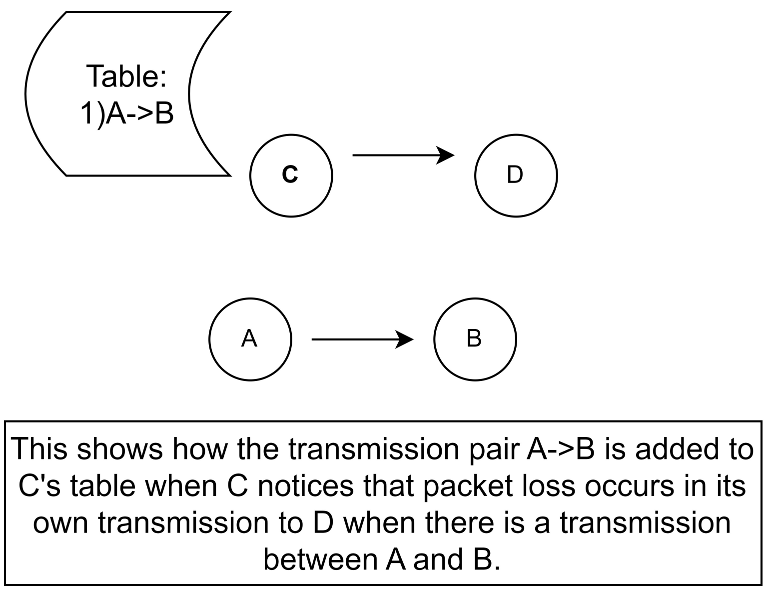

Fig. 2: Working of CMAP

M. Vutukuru *et al.* [11] have demonstrated their approach to implementing a conflict map for exposed node terminal problems. As illustrated in Fig. 2, each node 'C' in the network maintains a table that holds the sender and receiver pair 'A' and 'B' of some other transmission if 'C' transmits to some other node 'D' when there is an ongoing transmission between 'A' and 'B' and there is an observed decrease in throughput [17]. They built the table for each node based on node 'C', observing the packet loss details when another transmission is already going on nearby between 'A' and 'B.' This way, the 'C' node knows not to initiate conversation when another transmission between 'A' and 'B' is going. They have used the loss probability to add a pair to the table. The CMAP approach uses the conflict map to address collisions in the network.

Node 'C' consults its table before sending a message to node 'D'. When it finds that 'A' and 'B' are already in the table and that there is an ongoing transmission between them, it refrains from sending data to 'D'. Otherwise, if 'A' and 'B' are not in the table, it sends its message to 'D'. While the throughput has increased by 52 % in non-multi-hop environments, this approach may not function properly when the two senders are not within hearing range of each other. The network may suffer packet loss before the conflict map is built [11].

2.2 RTS/CTS Validation Technique

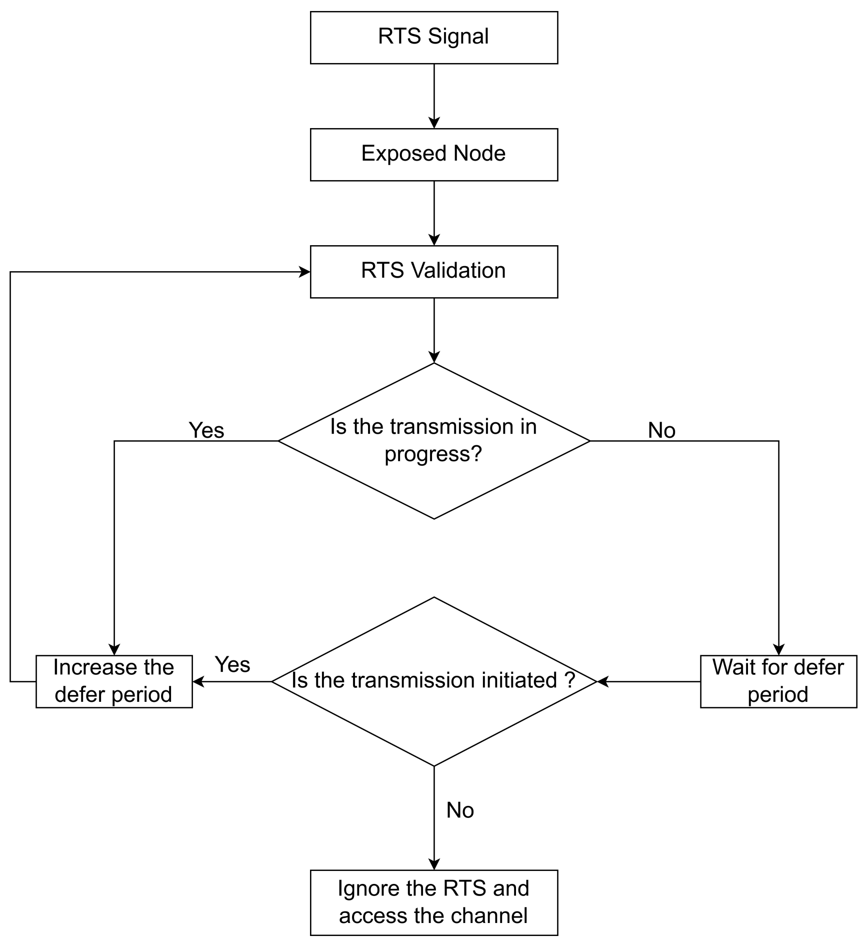

Fig. 3: RTS Validation Technique

S. Ray *et al.* [15] have implemented a technique to validate RTS signals. This approach can be analyzed using Fig. 3. On validation, the nodes not supposed to be the receiver nodes ignore the RTS signal. When the node receives an RTS signal, it checks whether the channel is idle. If it is not idle, it does not initiate transmission and waits until it becomes available. When the node receives the RTS signals, it checks whether the channel is idle. If it is not found to be idle, the receiving nodes initiate transmission. This is possible by assigning a small RTS defer time during which the neighboring nodes become inactive. This time duration is set to a very minimal value so that when the node does not sense a passive channel, it does not wait after this duration. The RTS defer period will increase if the channel is detected as busy. Since this RTS defer time has been set to a meager value, this reduces the chances of unnecessary deferment from data transmission [15]. Hence, it decreases the number of RTS signals that end up unresponding. This approach increased the throughput of the network by 13 packets. However, there might be unnecessary blocking due to overhearing [18].

2.3 Assignment of Dynamic Transmission Range

In this paper, M. M. Artimy *et al.* [2] present an efficient method to regulate the transmission range using vehicles' density in a particular VANETs radius. Accordingly, the authors have devised an algorithm that first finds the vehicle density and then calculates the network's transmission range to enhance vehicles' performance in VANETs. Generally, the minimum transmission range is calculated using graph algorithms for all the vehicles in the network. Afterward, each node is assigned a default transmission power for two situations corresponding to 1-lane and 3-lane roads. The transmission range must be maintained at a high level to accommodate the traffic when all vehicles intend to exchange data or packets through the same transmission range. The transmission range value can be maximum in an unimpeded traffic flow. However, the transmission range must adapt during traffic congestion to ensure effective communication. This adaptation is facilitated by considering the density F (Eq. 1), defined as the ratio of the time T_s during which test vehicles are entirely stationary for the total time T spent waiting in traffic.

$$F = \frac{T_s}{T} \tag{1}$$

According to the authors, if F = 0, indicating that vehicles are stationary throughout the traffic duration, the transmission range is set to its maximum. Otherwise, the transmission range is determined by the minimum value of Eq. 2 and 3:

$$Max_{TR}(1-K) \tag{2}$$

$$\sqrt{\frac{Max_{TR} \cdot \ln(Max_{TR})}{K} + \alpha \cdot Max_{TR}} \tag{3}$$

where, Max_{TR} is the maximum transmission range, K is the estimate of vehicle density and α is a constant [2]. This approach considers the dynamic nature of events and can be integrated with the present protocols easily. However, it might need to consider the exchange of beacon messages in the network [19].

2.4 Asymmetric Transmission Ranges for CTS and RTS

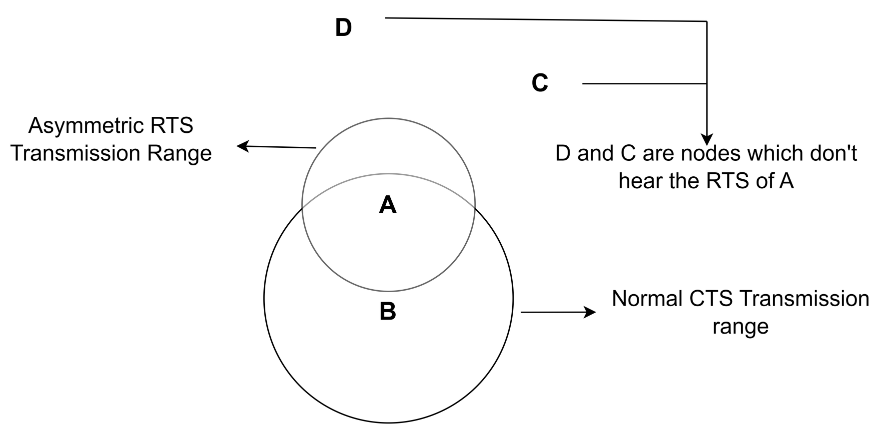

Fig. 4: Modified RTS Range

E. Weyulu *et al.* [16] use a reduced RTS transmission range to reduce the chances of an exposed node overhearing the RTS [16]. If the maximum RTS value set previously is crossed, then the RTS packet will be disposed of. This decreases the chances of a node becoming an exposed node, which leads to increased throughput. Here, as shown in Fig. 4, as the RTS signal from 'A' just has to reach the intended receiver (in this case, 'B'), a short RTS signal is sufficient. This is the Asymmetric RTS Transmission Range. 'A' sends back a regular CTS as before. However, the shorter RTS range removed the possibility of nodes 'D' and 'C' from being exposed nodes. It prevented them from going into the total backoff stage. The variable maximum RTS range is set based on certain factors, which cause all the packets with greater RTS range to be dropped even if they reach nodes 'D' and 'C'. The dropped RTS packets are much less than the proposed standard RTS/CTS method. The advantage of this method is that there is a significant increase in throughput. However, this method still causes some exposed nodes to exist when they occur within the range of the short RTS range, which cannot be avoided [16].

Table 1: Comparison of Existing Approaches

Metrics	**M. Vutukuru *et al.* [11]**	**S. Ray *et al.* [15]**	**M. M. Artimy *et al.* [2]**	**E. Weyulu *et al.* [16]**
Solving degree	Medium	High	High	Medium
Network efficiency	Relatively efficient	Inefficient	Inefficient	Slightly Inefficient
Set up cost	Low	Low	Medium	Low
Complexity	High	Medium	High	Medium
Scalability	Medium	Low	Medium	High

3 Design and Implementation

This section presents the implementation and detailed flow of the proposed solution, which mainly aims to dynamically adjust the transmission range of a node based on the vehicular density. Subsection 3.1. deals with the calculation of vehicle density in the vehicle's transmission range. Subsection 3.2 deals with the assignment of dynamic transmission range.

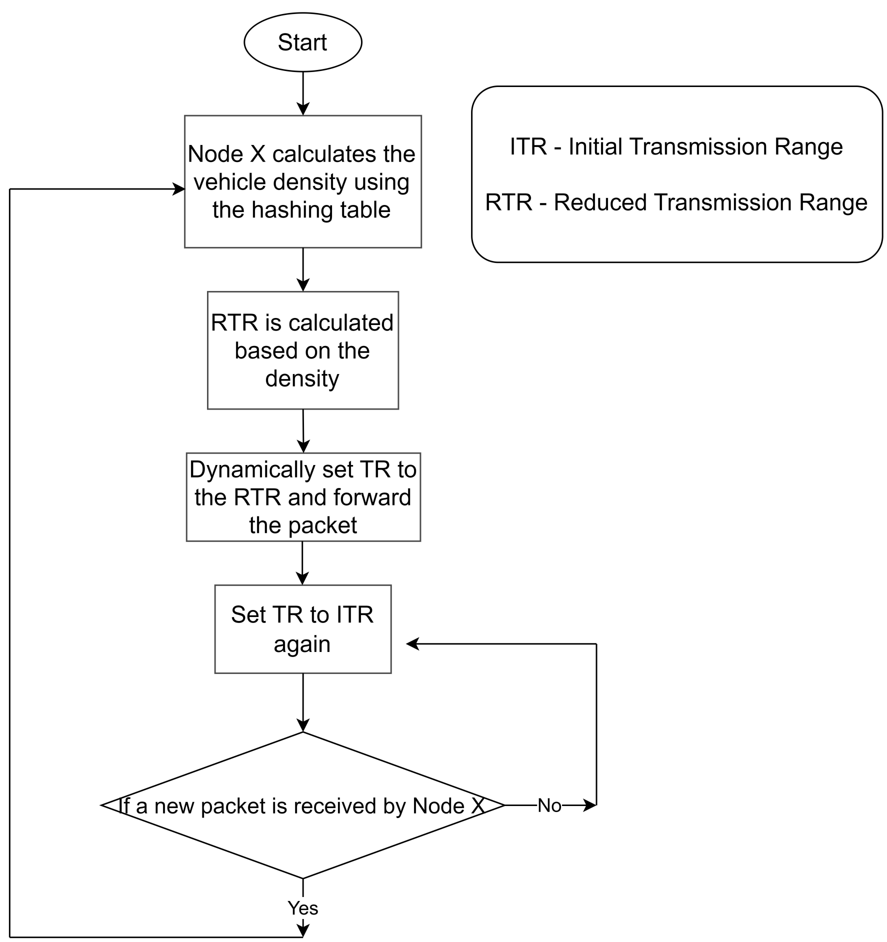

Fig. 5: Architecture of the Proposed Solution

3.1 Implementation of hashing table to calculate the Vehicle Density

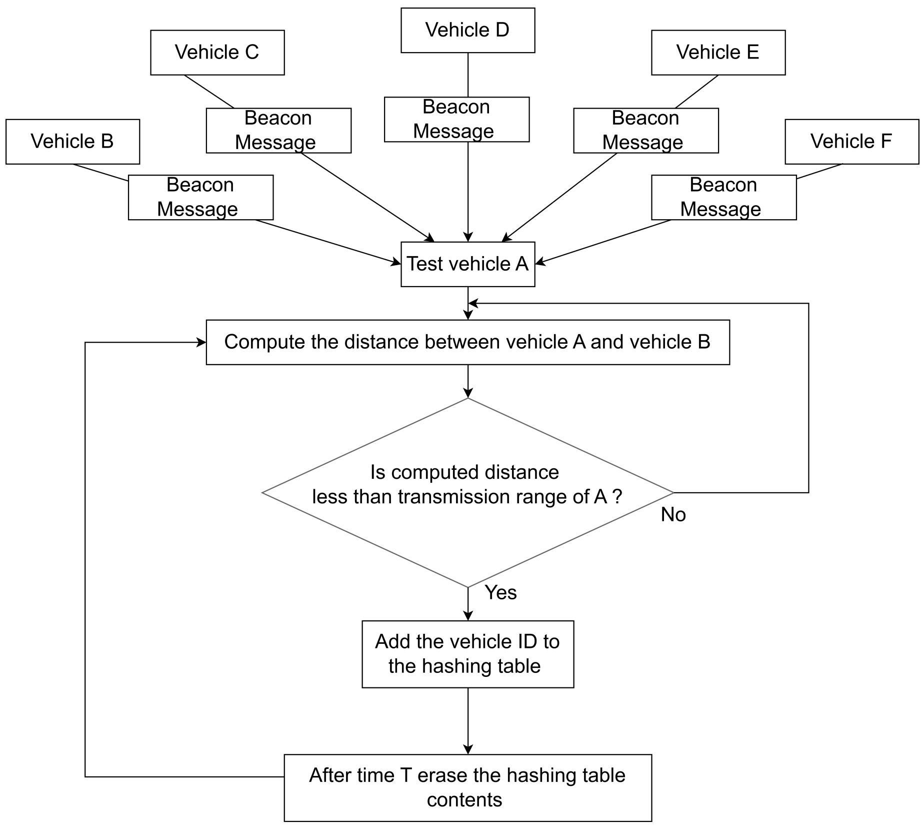

Fig. 6: Implementation of Hashing Table to Calculate the Actual Number of Vehicles

This approach uses the DSRC (Dedicated short-range communications) protocol to enable information exchange between the vehicles. DSRC protocol is a recent development in networking technology that provides tools for vehicle-to-vehicle communication involving cellular aids while being based on Wi-Fi technology. As shown in Fig. 5, each node calculates the immediate density of the nodes around it using the DSRC protocol. After this, the node's R_{TR} is computed based on the density obtained. Now, the node can transmit the packet within the reduced transmission range. After it transmits the packet, the node again sets its transmission range to the previous I_{TR} value until a new packet is received, upon which the process repeats.

Fig. 6 depicts the implementation of the hashing table for a test vehicle 'A'. In DSRC protocol, each vehicle in the network securely exchanges its heading direction and speed ten times each second. So, using this information, the other vehicles around this vehicle estimate the possible risk factor imposed by this vehicle. DSRC operates in the 5.9 GHz band [20]. This protocol operates in two modes: continuous and burst mode. This approach uses a continuous mode of operation to ensure consistent communication between the vehicles. The hashing table actively stores the identities of vehicles within the vehicle's transmission range. In the context of vehicle 'A', the Hashing Table resides within its On Board Units (OBUs), utilizing the available memory chips for storage. Vehicle 'A' would be continuously receiving beacon messages from the neighboring nodes. The message includes various parameters related to vehicle 'B', such as vehicle ID, vehicle location (latitudes and longitudes), transmission range, speed, and heading trajectories. This approach involves implementing a checking mechanism in the OBUs of vehicle 'A' that checks whether any vehicle exchanging a beacon message with it is available within its transmission range. Let us take TR_A as vehicle 'A's transmission range. Let B be the vehicle sending beacon messages to 'A'. Let (x_A, y_A) and (x_B, y_B) be the latitudes and longitudes of 'A' and 'B', respectively. Eq. 4 calculates the distance between vehicles 'A' and 'B'.

$$\mathrm{d}_{AB} = 2R\sin^{-1}\left(\sqrt{\sin^2\left(\frac{x_B - x_A}{2}\right) + \cos(x_A)\cos(x_B)\sin^2\left(\frac{y_B - y_A}{2}\right)}\right) \tag{4}$$

where, R - is the radius of the Earth and d_{AB} - is the distance between 'A' and 'B'. If d_{AB} obtained is less than TR_A, then the vehicle ID of 'B' is added to the Hashing Table of vehicle 'A'. Let TN (Eq. 5) represent the total number of vehicles within the transmission range of 'A'.

$$TN = \frac{n_d \times L \times TR}{S} \tag{5}$$

where, TN - is the total number of vehicles possible for the given transmission range TR, L - is the number of lanes, S - is the minimum separation, and n_d - is the number of possible directions [21]. Therefore, the vehicle density (K) (Eq. 6) is defined as the ratio of the number of vehicles present in the transmission range to the total number of vehicles permitted in the transmission range of 'A'.

$$K = \frac{AN}{TN} \tag{6}$$

where, AN - is the actual number of vehicles present (obtained from the hash table), and TN - is the total number of vehicles (Eq. 5).

3.2 Dynamic Transmission Range

In a practical algorithm, determining a power level would be preferred over a transmission range. The power level may assume any value within a set of possible power levels available to the wireless interface [22]. However, for easy comparison with the network's length and the distance between vehicles, dealing with the transmission range directly is necessary [22]. In this part of the paper, we utilize the vehicle density calculated in the previous section to adjust the transmission range dynamically. Additionally, we strive to persuade readers that decreasing the transmission range would result in the low-exposed node problem in real-life simulations.

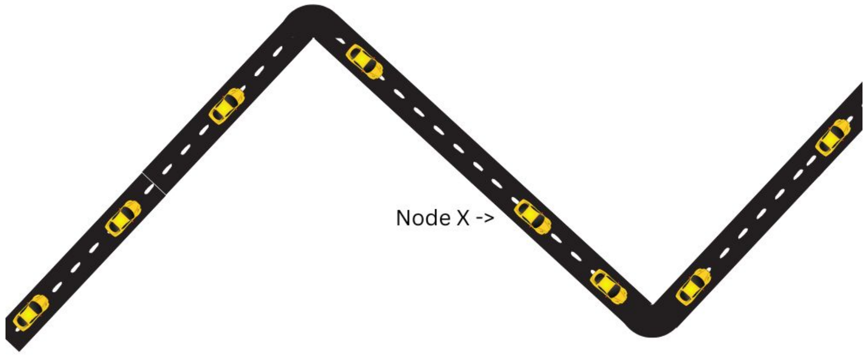

Fig. 7: Zig-Zag configuration for the SUMO simulation

One can actively control vehicle traffic flow and its associated parameters in a multi-lane system. In this context, free-flow traffic implies that all vehicles are initially at rest at the starting point. Later, vehicles start one after another from the initial point, with a fixed time slot separating each vehicle. Each vehicle moves with the same velocity and acceleration at any chosen point on the road but at different time intervals. A zig-zag patterned road, as shown in Fig. 7, is considered, which constantly varies the vehicle densities near each turn, thus aiding in varying the results and improving the analysis. Consider a node named 'X', where the results are presented. Since free-flow traffic is considered, the number of nodes that flow through any given point on the road will depend on the duration of the simulation. To measure the values, node 'X' is considered the seventh vehicle moving in the free-flow traffic. The simulation is run for fixed time slots within which density parameters are calculated. Once the simulation starts, vehicles accelerate on the straight part and decelerate near the turn, leading to variation in vehicle density in each part of the road. Considering the Initial Transmission Range (I_{TR}) of the vehicle, the number density of vehicles around node 'X' is calculated at each time interval of 100 milliseconds for the sake of explanation, wherein number density implies the number of vehicles within the transmission range of node X for a unit area within the transmission range.

Considering 35 time slots, each of 100 milliseconds, the number density of node 'X' is calculated at each slot and then plotted against the time slots. The position coordinates of the vehicles at a given slots of time are used to obtain the number density at that instance of time. The proposed method utilizes DSRC to calculate the density value. Now, the number density of the vehicles is dynamically obtained using the proposed method. The number density is plotted against the time intervals of 100 milliseconds. The term Reduced Transmission Range (R_{TR}) is used to denote the modified transmission range. A linear relation is used to calculate the R_{TR} using the I_{TR}. The vehicular density (K), which denotes the number density for this simulation, is utilized.

$$R_{TR} = I_{TR}(1 - K) \tag{7}$$

This will result in a maximum transmission range whenever the vehicular density is zero, i.e., when no vehicle is moving around node ‘X,’ and a reduced transmission range when the congestion of vehicles increases.

The concept revolves around optimizing the communication range of a node, which in turn affects the extent of interference with neighboring nodes. By reducing the transmission range of node ‘X,’ the aim is to limit the number of vehicles that node ‘X’ can broadcast to and communicate with at any given moment. This reduction in communication range aims to mitigate the “Exposed Node Problem," where excessive communication range can lead to interference and congestion among neighboring nodes. The essence lies in understanding that reducing node ‘X’s transmission range can effectively reduce the radius within which it can communicate with other vehicles. Consequently, fewer vehicles will fall within this reduced transmission range, reducing the likelihood of interference with neighboring nodes’ communications. This strategy alleviates the exposed node problem to a certain degree by creating a more focused communication environment. The proposed method is illustrated using a flowchart in Fig. 5. Upon forwarding the packet to the vehicles, the transmission range resets to normal or maximum transmission range. Hence, node ‘X’ instantaneously reduces the transmission range for forwarding the required packets whenever a new packet is received. Thus, RTR adapts to the new traffic condition each time a new packet is received.

4 Result and Analysis

This section deals with the results and analysis of the proposed solution for the exposed node problem obtained with the help of the SUMO simulator [23]. The position coordinates of each node in the laned configuration are fetched from the tool and used to calculate the vehicles’ density dynamically. A constant free-flow condition is set for all the configurations to ensure an effective comparison of the results. We varied the parameter (number of lanes) keeping the velocity and the acceleration of the vehicles constant, but differed by a fixed time slot. Simulation is run a total of 10 times, thus optimal results are presented in this section of the paper.

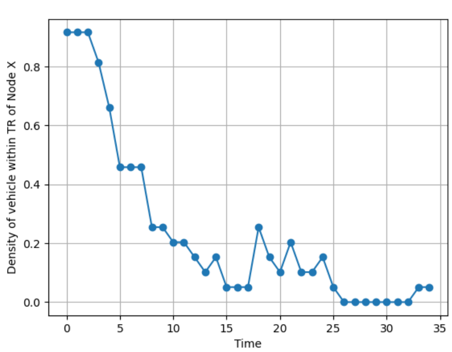

Fig. 8: Density of Vehicles

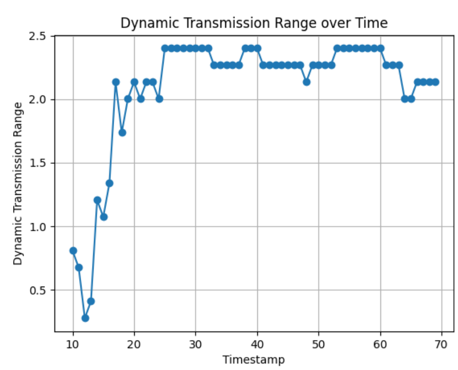

Fig. 9: Dynamic Transmission Range

The graph in Fig. 8 depicts the variation in the vehicle density over time for a single-lane configuration as shown in Fig. 7. Initially, the vehicle density is high, representing a highly congested network. The vehicle density around the test vehicle gradually decreases until the vehicle encounters a turn due to the zig-zag configuration, at which vehicles come into the vicinity of each other. Fig. 9 shows the variation of the transmission range against time for a single lane configuration as shown in Fig. 7. The dynamic transmission range denotes R_{TR}, obtained from equation 7. Since the vehicle density is initially large, the transmission range is lower, considering that the dynamic density will have a more significant value. Gradually, the vehicle density decreases, and the transmission range increases correspondingly.

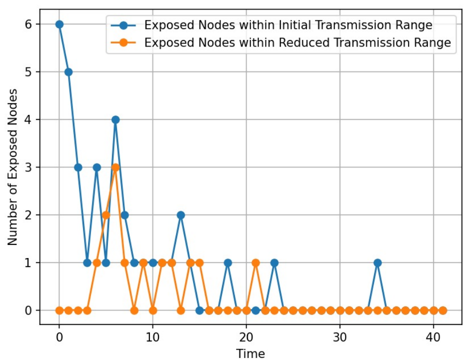

Fig. 10: Number of Exposed Nodes

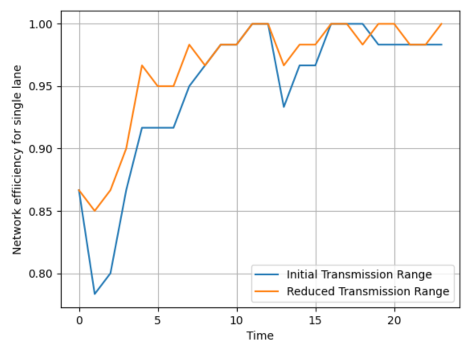

Fig. 11: Network Efficiency against Time

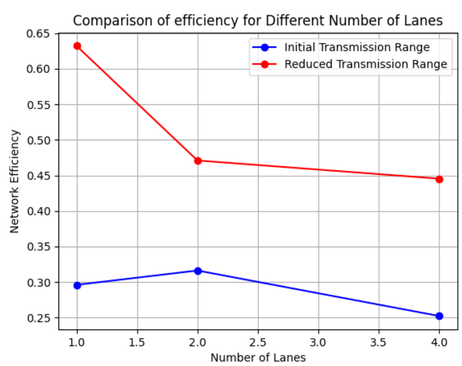

Fig. 12: Network Efficiency against Number of Lanes

Some nodes in the simulation are marked to showcase the results in terms of exposed nodes, which will start communicating with neighboring nodes at random instances. Thus, whenever these nodes come within the transmission range of node ‘X’, they become exposed, inhibiting their communication due to node ‘X’. A count of such exposed nodes is kept. Fig. 10 shows the relation between the number of exposed nodes and the time calculated for each time interval before and after using the proposed solution for single-lane zig-zag configuration.

We define the Network Efficiency for simulation using the number of nodes to explain the results,

$$NetworkEfficiency = \frac{T_n - T_{exp}}{T_n} \tag{8}$$

where T_n is the total number of nodes in the network, and T_{exp} is the total number of exposed nodes in the network.

Fig. 11 shows the relation between the network efficiency and time for a single-lane zig-zag configuration. To compare the results in different scenarios, two extra configurations of 2-lane and 4-lane roads are considered, with 2 and 4 respective free flow traffics in the corresponding lanes, thereby increasing the node count by twofold and fourfold compared to the single lane configuration. The simulation is run with equal time slots considering the same reference node ‘X.’ Further, the required number of nodes that were exposed to the I_{TR} and R_{TR} is obtained, and also the total nodes passing through the I_{TR} and R_{TR} are tracked. The Network Efficiency is plotted against the number of lanes using the parameters obtained to represent the simulations. Fig. 12 shows the relation between the Network Efficiency and the number of lanes used in the simulation for two different scenarios, i.e., with I_{TR} and R_{TR}. The graph clearly shows the increased efficiency in the case of R_{TR} as compared to I_{TR}. Moreover, the Network Efficiency increases initially but decreases after a certain number of lanes. This is due to the congestion in traffic, which only increases as the number of lanes increases. Congestion leads to more exposed nodes and thus decreases the overall Network Efficiency. In Fig. 11, the Network Efficiency increases as the overall density decreases, as shown in Fig. 8, which reduces the vehicle’s transmission range.

5 Conclusion and Future Work

The objective of the paper was to demonstrate how dynamically varying the transmission range of a node in a VANET limits the number of exposed nodes. The paper utilizes a hashing technique to store vehicle IDs within a node’s transmission range. The simulation was performed for multi-lane scenarios. The number of nodes in the network varied according to the free flow parameter and the number of lanes. The resulting graphs show an increase in the Network Efficiency and a decrease in the number of nodes exposed. However, the work done in this paper is limited to less congested network conditions. Future work may be done using a dedicated simulation tool like NS-2 to assess the average delay properly.

References

1. S. K. Sandeep N. Kugali, Vehicular ADHOC Network (VANET):-A Brief Knowledge, https://www.ijert.org/vehicular-adhoc-network-vanet-a-brief-knowledge, [Accessed: 23-01-2024] (2020).
2. W. J. P. Maen M. Artimy, William Robertson, Assignment of dynamic transmission range based on estimation of vehicle density, https://dl.acm.org/doi/abs/10.1145/1080754.1080761, [Accessed: 10-02-2024] (2005).
3. R. Tomar, M. Prateek, , G. H. Sastry, Vehicular Adhoc Network (VANET)- An Introduction, https://hal.science/hal-01496806/document, [Accessed: 23-01-2024] (2017).

4. D. D. Manjusha Abhijeet Deshmukh, Challenges in Vehicle Ad Hoc Network (VANET), https://www.researchgate.net/publication/326250676_Challenges_in_Vehicle_Ad_Hoc_Network_VANET, [Accessed: 23-01-2024] (2014).
5. B. Sharma, M. Satya, P. Sharma, R. S. Tomar, A Survey: Issues and Challenges of Vehicular Ad Hoc Networks (VANETs), https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3363555, [Accessed: 23-01-2024] (2019).
6. R. K. Kamini, VANET Parameters and Applications: A Review, https://globaljournals.org/GJCST_Volume10/vanet-parameters-and-applications-a-review.pdf, [Accessed: 23-01-2024] (2010).
7. L. A. T. Kosch, C. Schwingenschlogl, Information dissemination in multihop inter-vehicle networks, https://www.semanticscholar.org/paper/Information-dissemination-in-multihop-inter-vehicle-Kosch-Schwingenschlogl/c027e83b2273f5c868ad6e926ec9dc06ee47d6fb, [Accessed: 23-01-2024] (2002).
8. S. M. Vishal Kumar, Narottam Chand, Applications of VANETs: Present 'I&' future, https://www.researchgate.net/publication/260459800_Applications_of_VANETs_Present_future, [Accessed: 23-01-2024] (2013).
9. S. S. L. Usman Ali Khan, Multi-layer problems and solutions in VANETs: A review , https://www.researchgate.net/publication/331045084_Multi-layer_problems_and_solutions_in_VANETs_A_review, [Accessed: 10-01-2024] (2019).
10. O. Dousse, P. Thiran, M. Hasler, Connectivity in ad-hoc and hybrid networks (2002). doi:10.1109/INFCOM.2002.1019356.
11. M. Vutukuru, K. Jamieson, H. Balakrishnan, Harnessing exposed terminals in wireless networks, https://www.cse.iitb.ac.in/~mythili/research/gradschool/cmap.pdf, [Accessed: 10-01-2024] (2008).
12. S. Hemalatha, N. Patel, A. Kumar, N. K. Jain, G. V. Narayanan, M. Manwa, H. Pallathadka, R. P. Chinhewadi, MANET Hidden and Exposed Terminal - Challenges and Survey, https://ijritcc.org/index.php/ijritcc/article/view/7593, [Accessed: 23-01-2024] (2023).
13. R. K. T. L. Singal, Prachi Sharma, MAnalysis of Exposed Node Problem and Security Concerns in Adhoc Networks , https://tmg.chitkara.edu.in/2010/analysis-of-exposed-node-problem-and-security-concerns-in-adhoc-networks/, [Accessed: 22-03-2024] (2023).
14. D. B. P. Santi, Solving the Hidden Terminal problems Using Directional-Antenna Based MAC Protocol for Wireless Adhoc Networks, https://www.semanticscholar.org/paper/An-evaluation-of-connectivity-in-mobile-wireless-ad-Santi-Blough/e93d8a77f46f48351ce69dbf3691f2c9c215ffd2, [Accessed: 23-01-2024] (2002).
15. J. B. C. Saikat Ray, D. Starobinski, RTS/CTS-Induced Congestion in Ad Hoc Wireless LANs, https://people.bu.edu/staro/wcnc-ray.pdf, [Accessed: 23-01-2024] (2003).
16. M. W. K. Emilia Weyulu, Masaki Hanada, Optimizing RTS/CTS to Improve Throughput in Ad Hoc WLANs, https://www.researchgate.net/figure/Asymmetric-RTS-CTS-transmission_fig7_320012604, [Accessed: 10-02-2024] (2017).
17. A. Eliab, Y. Kim, J. Lee, J.-G. Lee, J. So, G-DCF: Improving System Spectral Efficiency through Concurrent Transmissions in Wireless LANs, https://www.hindawi.com/journals/wcmc/2019/5427573/, [Accessed: 23-02-2024] (2019).
18. M. M. Björn Scheuermann, Christian Lochert, Implicit hop-by-hop congestion control in wireless multihop networks , https://www.sciencedirect.com/science/article/abs/pii/S1570870507000157, [Accessed: 08-02-2024] (2008).
19. M. Nabil, A. Hajam, A. A. Abdelouahad, A. Haqiq, Improving Beacon-Based Routing Protocols Using Dynamic Coverage Area Determination, https://ieeexplore.ieee.org/document/9966459, [Accessed: 05-02-2024] (2022).
20. J.-K. Bae, M.-C. Park, E.-J. Yang, D.-W. Seo, Implementation and Performance Evaluation for DSRC-Based Vehicular Communication System , https://ieeexplore.ieee.org/document/9292911, [Accessed: 05-02-2024] (2021).
21. D. B. Rawat, D. C. Popescu, G. Yan, S. Olariu, Rawat, Danda B. and Popescu, Dimitrie C. and Yan, Gongjun and Olariu, Stephan, https://ieeexplore.ieee.org/abstract/document/5703081, [Accessed: 11-02-2024] (2011).

22. D. B. P. Santi, An evaluation of connectivity in mobile wireless ad hoc networks, https://ieeexplore.ieee.org/document/1028890, [Accessed: 23-01-2024] (2002).
23. R. H. Michael Behrisch, SUMO(Simulation for Urban Mobility), https://eclipse.dev/sumo/, [Accessed: 23-01-2024] (2002).