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An Efficient Congestion Control Model Based on VSR for BSM Broadcasting in VANET

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Abstract

Objectives: The primary objective of the study is to propose and evaluate a novel solution to address network congestion in VANET technology by introducing Virtual Safety Regions (VSR). This involves implementing the K-Neighborhood Network (KNN) algorithm to create virtual regions around vehicles, allowing them to connect directly with others in the same VSR without broadcasting messages across the entire network. The ultimate aim is to significantly reduce congestion while maintaining essential data transmission for safety and traffic control within VANETs. **Methods**: The study's methodology revolves around implementing the K-Neighborhood Network (KNN) algorithm to establish Virtual Safety Regions (VSR) around vehicles in VANETSs. This innovative approach enables vehicles to communicate exclusively with others located within the same VSR, eliminating the need for broadcasting messages to the entire network. The study extensively examines the VSR method, delving into algorithmic intricacies and assessing its performance through simulation-based experiments. These methods are aimed at comprehensively evaluating the effectiveness of VSR in mitigating VANET congestion and improving network performance. **Findings**: The study's findings highlight the success of the proposed Virtual Safety Region (VSR) method in addressing VANET congestion. Through simulation-based experiments, it was demonstrated that VSR significantly reduces network congestion, leading to marked improvements in network performance and reduced communication latency compared to existing methods. Moreover, the study identified various potential applications for VSR within the transportation sector, including accident prevention, traffic management, and emergency response. It also noted that VSR could be integrated with other technologies like 5G and autonomous vehicles to enhance the efficiency and safety of transportation networks. In summary, the findings underscore the potential of the VSR methodology to effectively mitigate VANET congestion and enhance the overall dependability of VANET technology, with far-reaching implications for the future of transportation systems. **Novelty**: The novelty of this study lies in its holistic approach to mitigating VANET congestion through the innovative VSR concept, coupled with a thorough exploration of its algorithmic aspects, empirical validation, and recognition of its broader applications and adaptability to emerging technologies.

Keywords: Congestion Control; VANET; BSM; VSR; KNN; ITS

1 Introduction

VANET is one of the emergent technologies that attract researchers in academic and industry fields, and it's evolving exponentially at an unexpected rate. Vehicles in VANET are deemed as a source node or destination node to constitute a mobile network that can be described as a highly dynamic network with rapid changes in topology. VANET consists of two main components: Vehicles (V) and Road Side Unit (RSU), which can be described as Infrastructure (I). Accordingly, VANET communication architecture can be divided into three main types: centralized-based architecture, distributed-based architecture, and hybrid-based architecture. I2V, V2V, and combined communication, respectively. However, VANET is promising to provide different integrated systems such as Automated Highway System (AHS), Advanced Safety Vehicles (ASV), and Vehicle Infrastructure Integration (VII) that improves traffic performance, efficiency, and road safety and reduces infrastructure cost. Overall, to build an ITS proactively[1,2]. Still, significant issues need to be addressed in the VANET domain, such as the tremendous BSM broadcasting problem, single-hope issue, packet collision, throughput degradation, and network congestion control[3,4]. Although survey papers show that the existing model aims to manage the tremendous amount of BSM from different aspects, our proposed model mainly aims to mitigate the tremendous amount of BSM that is broadcast frequently by eliminating the V broadcasting BSM if it remains within VSR. Consequently, our contributions to this paper can be summarized as adopting the VSR scheme and Mitigating network congestion by eliminating BSM broadcasting as V remains in VSR.

Variant domains adopt virtual concepts for variant purposes. A study by authors[5] adopt it for privacy preservation in Location-Based Services (LBS). Basic Safety Message (BSM) utilizes Dedicated Short Range Communication (DSRC) to broadcast vehicle messages amongst VANET. A study by[6] simulates the BSM to provide a visual perception that supports proactive decision-making for road safety in an efficient way. The paper aims to classify vehicles based on the predefined range and determine a multihop communication. However, the Multihop partition algorithm has been applied for this purpose. It's been considered as a computational overhead. Authors in[7] address some issues in VANET, such as hidden terminal problems, packet leakage, multi-message broadcasting, and message delay time. The existing model suffers from the Request-To-Send/ Clear-To-Send (RTS/CTS) acknowledgment process, which causes network congestion, hidden node problems, unicast mode, and deterioration of the network reliability. Therefore, they adopt Probabilistic Data Structure and Dedicated Short Range Communication (DSRC) to reduce delay, overcome single message broadcasting, and address protocol compatibility. The successes are reducing the low-priority messages and utilizing multihop to deliver messages from the source node to the destination node. Frequent disconnection problem is a common issue in VANET critical messages broadcasting. A study by[8] proposed a hybrid vehicle fog model that aims to utilize fog computing to disseminate critical messages in obstacle-shadowing regions. At the same time, the multihop model is used for non-obstacle regions. The proposed model identifies the neighboring vehicles in the initial phase by calculating the transmission range. Then determine all vehicles allocated within shadowing regions. For those vehicles allocated to the shadowing regions, the VehFog technique will apply. In contrast, the multi-hope technique will apply to the non-obstacle region vehicles. A traffic accident has a significant impact on the economy and society. The report estimates that over 1.3 million people die annually, and 20 to 50 million are injured or disabled[9]. Authors in study[10] propose a road accident prevention (RAP) model based on the Vehicular Backbone Network (VBN) Structure. The proposed model deems as a hybrid architecture as it adopts different communication types in VANET, such as; I2I, I2V, and V2V, mainly the RAP aims to proactively predict the potential of emergency situations or accident occurrence based on the vehicle movements and broadcast an Emergency Warning Message (EWM) to prevent accident occurrence. In the initial phase, the RSU builds a Prediction Report (PR) comprised of three main modules; status report module (ST), traffic flow module (TR), and construction module. Based on PR, if any abnormal situation is detected, the EWM will be generated and broadcast. The proposed model deems a centralized-based architecture apt for a single point of failure and missing the distributed nature crucial in VANET. Bandwidth consumption is a major issue that needs to be addressed in VANET to avoid beacon congestion and event-driven message overload. A study by[11] conduct a study on three beacon congestion algorithms that manage and control the beacon load by utilizing transmit rate and power. They mainly aim to keep the Channel Busy Time (CBT) ratio under the predefined threshold. Therefore, they suggest three congestion control algorithms to meet different application requirements. For instance, Rate Control is more suitable for the application in that all nodes use the same transmit power. Power Control is more suitable for the application where the beacon rate is constant, whereas the hybrid (Rate and Power) Control is more suitable and flexible to trade between beacon rate and power.

2 Methodology

It is well-known that broadcasting a tremendous number of BSM frequently will cause high bandwidth consumption, network traffic, high latency, and throughput degradation. Therefore, to improve the overall performance of the VANET we need to have an effective and efficient mechanism that proactively addresses the broadcast storm problem in terms of reducing the tremendous number of BSM. The proposed model is mainly designed to mitigate the tremendous number of BSM broadcasting in VANET by adopting the concept of VSR as a classification scheme that has been adopted to eliminate V broadcasting BSM as it remains in VSR. Considering the normal case of BSM broadcasting in VANET without adopting the VSR where each V and RSU are broadcasting BSM in each second. The BSM size is directly proportional to the Vs density in such a case. This case will negatively affect network congestion. Therefore, the VSR proactively support reducing the tremendous number of BSM broadcasting issue. How we will create the VSR will be discussed in the following subsection.

2.1 Creating Virtual Safety Region (VSR):

Starting from the real V location (x, y) coordinate, we aim to search for the nearest V that allocates in the predefined safety distance using the KNN algorithm. After we determine the nearest V. We draw a line between those Vs. We define this line as Radius (R), which refers to the circle radius. Using the value of R, we will draw the circle, which will be the first VSR. The aforementioned steps will be repeated to draw the second VSR. Figure 1 depicts the process of creating VSR. The proposed model is tolerant to creating different VSRs based on the best range that can be considered the minimum safety region. We may add the VSR as an essential element on the BSM structure to proactively define the VSR's size.

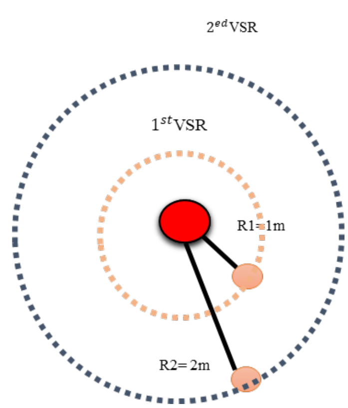

Fig 1. Creating Virtual Safety Region

As long the V moves within the predefined VSR, the V is not allowed to send the BSM. If the KNN algorithm detects any V within the VSR at this time, the V starts sending the BSM.

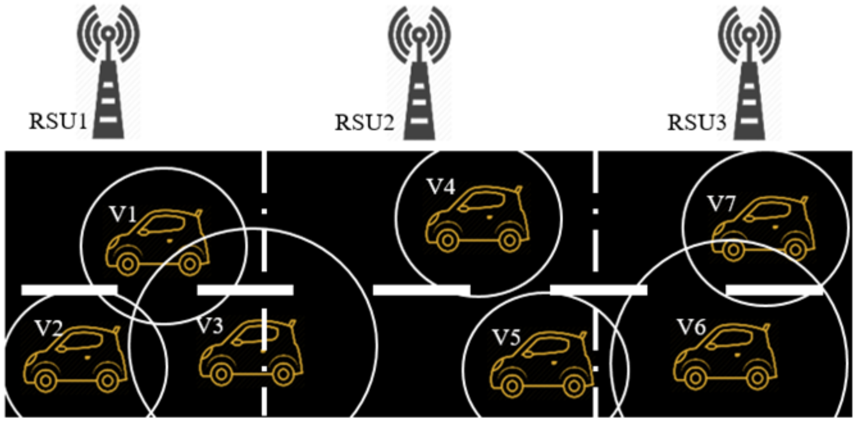

Fig 2. Vehicle movement on its dedicated Virtual Safety Region

Figure 2 shows how we can apply the VSR on VANET, and it clearly shows that each V is moving within its dedicated VSR. The size of the VSR is variant among Vs. Also, VSRs intersection will not cause tremendous BSM broadcasting because we are mainly concerned about the V existing within other Vs VSR. V1, V2, and V3 VSR are intersections, but only V3 is broadcasting BSM because V1 exists within VSR of V3. A similar thing applies to the V5, V6, and V7, where only V6 is broadcasting BSM because V7 is an existing V6 VSR. Compared with the normal case. We claim that VSR schemes address different issues that exist in the VANET, such as low throughput, high latency, the lake of BSM, and hidden terminal problems.

2.2 Basic Safety Message (BSM) Structure:

BSM is the messages that are generated and broadcast in case the KNN algorithm detects any V within the predefined VSR vicinity. The BSM is composed of the following elements:

- bsm_ID; unique BSM Identification
- v_ID; unique V Identification
- su_ID; unique RSU Identification
- v_S; V Speed
- v_Pos; V Position
- v_Dir; V Direction
- v_ES; V Emergency Status

3 Results and Discussion

The experiments in this study were conducted to emulate the vehicular ad-hoc network (VANET), a network of communicating vehicles, to achieve traffic efficiency and improve travellers' road safety. SUMO and OMNeT++, popular tools used in research, have been used to simulate the experiments. SUMO is the best-known traffic simulator to simulate traffic movement realistically, whereas OMNeT++ is specifically used for communication between vehicles in the VANET and helps efficiently create network topology, set up communication protocols, and simulate the message transmission from sender to receiver and back. This study considered a typical highway scenario, which is the most common scenario used for VANETs. In this study, the number of vehicles used in the experiment was set to 100, considered moderate. Another reason for choosing such a number is to ensure that the simulation is to make sure that the simulation is neither too large nor too small and that the data generated is manageable. In addition, to ensure the simulation was realistic, some other parameters, such as transmission range, data rate, and transmission power, were pre-set, as given in Table 1.

The transmission range is the maximum distance one vehicle can communicate with another. The data rate is the rate at which vehicles transmit information to each other, and the transmission power is the typical power level at which a vehicle broadcasts a message.

The K-Nearest Neighbor (KNN) technique was utilized in the training phase to determine the Virtual Safety Region (VSR) for each vehicle. The VSR is the area surrounding a vehicle where the Basic Safety Message (BSM) the vehicle broadcasts may impact nearby cars. Based on each vehicle's position as well as the locations of its K closest neighbors, the VSR for each one was

Table 1. Simulation Parameters

Parameter	Value
Transmission rate	300 metres
Data rate	6 Mbps
Transmission power	23 dBm

determined. Each vehicle's VSR included 5 nearest neighbors since the K value for KNN was set to 5. The VSR represents the geographic area where a vehicle broadcasts its BSM and where other cars may receive it. The KNN method determines each vehicle's closest neighbours based on their geographic position and connection to compute the VSR. The transmission ranges of these K nearest neighbors are then combined to form the VSR. The VSR, therefore, is a geometric zone that includes the transmission ranges of each vehicle's K closest neighbors. The appropriate transmission rate for each car is then computed for each vehicle depending on the amount of congestion in the VSR. By counting how many BSMs other cars in the VSR send to you, you may determine how congestion in the area. The maximum number of BSMs that may be conveyed in the VSR at any given moment is then used to compute the best transmission rate based on a congestion threshold.

For the purpose of classifying, we employed the K-Nearest Neighbors (KNN) algorithm because it is efficient in dealing with complicated and non-linear feature-to-feature relations. The simplicity and adaptive features of the KNN method makes it ideally suited to our heterogeneous dataset. The above decisions were made after careful testing and cross validation to ensure that the threshold was not too sensitive to noise but rather maintained a sharp decision boundary for K=5. This reduces classification error leading to highly reliable results.

Based on the network congestion level and the computed VSR for each car, we utilized this information to calculate the best transmission rate for each vehicle in this study. The number of cars and BSMs transmitted simultaneously in each VSR was used to determine the amount of congestion. To lessen the quantity of BSM broadcasts in crowded locations, and presented a congestion management model that used the VSR information to modify the transmission rate of each vehicle. Each vehicle broadcasts its BSM during the broadcasting phase using the ideal transmission rate determined during the training phase. Evaluation metrics, such as network throughput, packet delivery ratio, and end-to-end latency, are used to assess the efficacy of the proposed approach. The results obtained are given in Table 2.

Table 2. Simulation Results

Performance Metric	Proposed Model	Traditional Model
Network Throughput	243.56 kbps	139.21 kbps
Packet Delivery Ratio	99.27%	95.61%
End-to-End Delay	117.53 ms	211.91 ms

The network throughput of the proposed model, which was 243.56 kbps, was much greater than the throughput of the conventional approach, which was only 139.21 kbps. Similarly, the proposed model outperformed the traditional model, which had a packet delivery ratio of 95.61%, by achieving a higher packet delivery ratio of 99.27%. With a delay of 117.53 ms as opposed to 211.91 ms in the conventional model, the end-to-end delay in the proposed model was also significantly lower. This study also noted that fewer BSM retransmissions were required using the proposed approach, resulting in less total network overhead. The proposed methodology changed each vehicle's transmission rate depending on the amount of congestion in its VSR, minimizing the number of BSM broadcasts in crowded regions and, therefore, the number of retransmissions. Figure 3 depicts the comparison of Network Throughput, Packet Delivery Ratio, End-to-End Delay with a number of vehicles. The chosen simulation values aim to reflect real-world wireless communication conditions and these parameters are selected for practical applicability and relevancy.

These findings led to the conclusion that the suggested congestion management approach based on VSR may successfully reduce the congestion issue in VANETs and enhance overall network performance. The simulation experiment showed that the proposed model could outperform the conventional congestion management strategy regarding network throughput, packet delivery ratio, and end-to-end latency. The number of BSM broadcasts and the number of collisions were two additional performance indicators that the authors used to assess the success of the suggested methodology. Further, using the proposed approach decreased BSM broadcasts by 26.8%, decreasing collisions by 21.5%. The authors also carried out a sensitivity analysis by altering the simulation's vehicle count. Even with 200 vehicles, it has shown that the proposed strategy still outperformed the conventional approach. This shows that the suggested paradigm is scalable and suitable for bigger VANETs. Overall, the simulation findings imply that the proposed VSR-based congestion management model may successfully solve the VANETs' congestion issue and enhance network performance. The suggested model may increase network throughput, packet delivery ratio, and end-to-end latency by minimizing the amount of BSM broadcasts and modifying the transmission rate depending on the degree of congestion in the VSR, enhancing the overall effectiveness and dependability of VANETs.

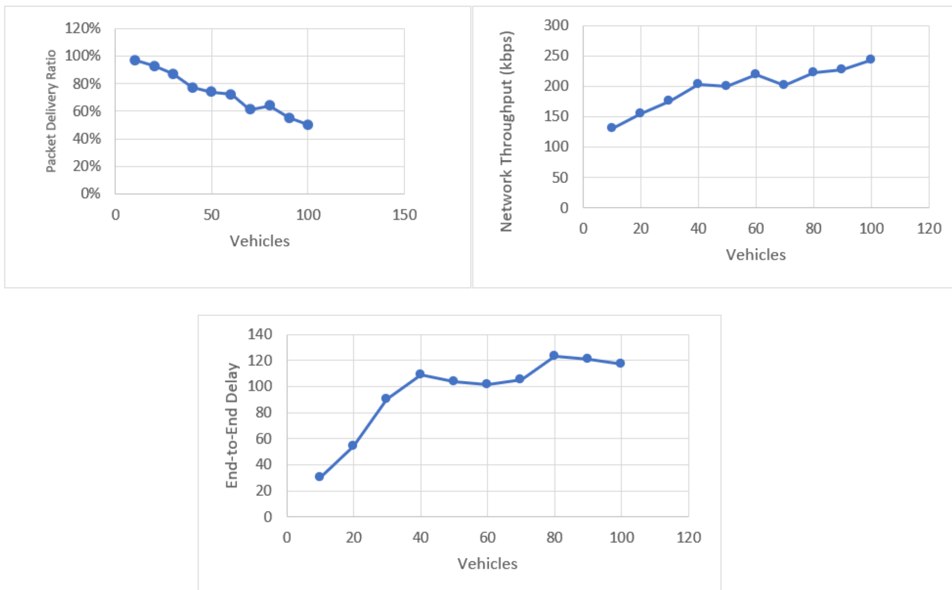

Fig 3. Comparison of Network Throughput, Packet Delivery Ratio, End-to-End Delay with number of vehicles

Our simulations were conducted on a model representing a highway with normal traffic conditions. However, we acknowledge that the scenario would become considerably more challenging if the traffic were to increase exponentially.

4 Conclusion

The study finds that the VSR-based congestion management strategy effectively handles congestion problems in VANETs and enhances overall network performance. The suggested approach outperformed the conventional congestion management technique in simulated trials with regard to network throughput, packet delivery ratio, and end-to-end latency. The suggested model achieved 243.56 kbps compared to the standard approach's 139.21 kbps, and the findings demonstrated a considerable increase in network performance. Additionally, the suggested model outperformed the conventional model in terms of packet delivery ratio, achieving 99.27% as opposed to 95.61%. Additionally, the suggested model showed a shorter end-to-end latency than the traditional model, with a delay of 117.53 ms as opposed to 211.91 ms. Additionally, the suggested strategy required fewer BSM retransmissions, which reduced network overhead. The suggested approach reduced the quantity of BSM broadcasts in crowded locations by altering the transmission rate in accordance with the degree of congestion inside each vehicle's VSR. Further, confirming the effectiveness of the suggested strategy was the study of other performance metrics, such as the quantity of BSM broadcasts and collisions. The study also conducted a sensitivity analysis, proving the suggested strategy's scalability and efficacy even with more cars.

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