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RESEARCH ARTICLE

A Technique for Efficiently Controlling Centralized Data Congestion in Vehicular Ad Hoc Networks

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Abstract – Vehicular Ad Hoc Networks (VANETs) belong to a distinct classification of wireless ad hoc networks. These networks are a subset of MANET networks used to communicate in ITS systems. Like MANET, VANETs do not have a specific structure, and the network nodes represent moving vehicles. The driver's decision, high speed, and continuous movement of cars have imposed unique characteristics on these networks. There are also new challenges, such as scalability, data routing, information broadcasting, QoS, and security. The rapid velocity of vehicles results in a significant frequency of VANET topology alterations. At the same time, the slow acceleration of cars can result in a substantial traffic concentration and an elevated likelihood of data collisions, leading to congestion. This paper proposes a new strategy for data congestion control. Upon identifying the network congestion, the proposed method resolves the congestion by emphasizing the minimal rate of the loss of packets (the quantity of dropped packets) by solving the optimization problem. In fact, after modelling the congestion and solving the problem, the data transmission rate is determined to minimize packet loss. The proposed method is compared with prominent data congestion control methods in networks such as CSMA/CA to evaluate the performance. The evaluation parameters include the network service quality, including the number of lost packets, throughput, and delay. The evaluation results indicate improvement in the network.

Index Terms – Vehicular Ad Hoc Networks, Congestion Control, Optimization, VANET, MANET Networks, CSMA/CA.

1. INTRODUCTION

The development of vehicular wireless communication for traffic detection and reduction plays a crucial role in modern transportation systems. Vehicular Ad hoc Networks (VANETs) are communication systems that enable data exchange between vehicles and roadside units (V2I communication) through the Dedicated Short-Range Communication (DSRC) protocol, as well as between vehicles (V2V communication). However, the vehicular environment presents several challenges that may hinder communication in VANETs [1].

VANETs are a core component of intelligent transportation systems (ITS) and have shown great promise for future generations. The significance of this technology lies in its direct impact on car safety, which is increasingly becoming a focus of modern transportation solutions. As advancements in science and technology continue, there is a growing effort to optimize vehicle performance through communication technologies, which could revolutionize industries such as transportation, car insurance, and road management. Achieving this requires improving network efficiency and design, with a strong emphasis on ensuring service quality in the provided services [2].

VANETs have two main applications: 1) beacon messages and event-driven messages, which are broadcast over the Control Channel (CCH) for safety applications, and 2) applications that do not prioritize safety, which send messages through the Service Channel (SCH), such as notifications related to traffic congestion and parking availability. A primary concern with VANETs is the congestion of wireless channels, as this directly affects the transmission of traffic data and the overall resilience of the network. This issue arises when a vehicle sends a large amount of data or when multiple vehicles simultaneously send packets over a wide region, leading to congestion due to limited capacity and a high number of buffer channels. This results in a communication burden that reduces the network's data delivery rate and negatively impacts the Quality of Service (QoS), particularly in terms of throughput, latency, and packet loss [3].

In VANETs, due to the high mobility of vehicles, special conditions arise when many cars gather in specific areas, such as at red lights. These conditions lead to congestion and data disruption. When packets reach a router node, they may not be forwarded, causing the router to discard them. This not only wastes network resources but also degrades service quality. As mentioned, congestion in these areas is a primary cause of packet drops by router nodes. When the network's capacity is insufficient to handle the traffic load, packet loss occurs, significantly reducing the network's operational efficiency. Therefore, congestion control is vital to avoid these issues and ensure reliable data delivery. Additionally, monitoring congestion is crucial for minimizing packet loss, improving network fairness, and ensuring interoperability across different standards and protocols [4].

VANETs confront considerable issues in terms of wireless channel congestion, which has a direct impact on traffic data transmission and network performance. These issues emerge when a vehicle sends a big amount of data or when numerous vehicles send packets across a vast area at the same time, causing congestion. Limited network capacity and a large number of buffer channels exacerbate the problem, resulting in increased communication loads, lower data delivery rates, and deteriorated Quality of Service (QoS), particularly in terms of throughput, latency, and packet loss [3].

Furthermore, in VANETs, the increased mobility of vehicles can cause congestion and data disturbance, particularly in regions where many vehicles congregate, such as at traffic signals. Under these conditions, router nodes may fail to forward packets, causing them to be rejected. This not only consumes network resources, but also drastically reduces service quality, affecting the network's overall functionality. As a result, congestion control algorithms are crucial for reducing packet loss, assuring consistent data delivery, and increasing network operating efficiency.

The proposed solution to this challenge works as follows: At intersections, vehicles stop at red lights and send their data to roadside units (RSUs). The RSUs centrally determine the transmission parameters and rates, which are then communicated to the vehicles. Based on the control data from the RSUs, the vehicles adjust their transmission parameters and send their data. Upon receiving packets from the vehicles, the RSU checks for congestion based on the number of packets received. In the event of congestion, the RSU broadcasts a signal, alerting the vehicles about the congestion. An optimization model is then implemented to determine the transmission parameters and minimize packet loss. By adjusting the sending rate, the model ensures that the maximum number of packets are transmitted in the shortest time, reducing packet loss and improving overall network performance.

In this paper, we present a novel approach to addressing congestion control in Vehicular Ad hoc Networks (VANETs). The core contributions of this work are as follows:

- We introduce a dynamic congestion control algorithm specifically designed for high-mobility environments in VANETs, where traditional methods often fail due to the unique challenges of wireless communication in vehicular networks.
- We develop an optimization model that minimizes packet loss by adjusting the transmission rates based on real-time congestion information. This model uses roadside units (RSUs) to monitor congestion and dynamically control the communication parameters of vehicles.
- We provide an extensive evaluation of the proposed mechanism under typical VANET scenarios, demonstrating its effectiveness in reducing congestion, minimizing packet loss, and enhancing network throughput.

The rest of the article is divided into the following sections.

We discussed the existing literature on controlling centralized data congestion in vehicular ad hoc networks (VANets) in Section 2. Section 3 describes the research methodology for this work. It presents the Congestion detection, Collected data control, Congestion control, and Optimization model. The simulation platform is then presented and evaluation results are given in Section 4. Finally, the conclusion of the research is presented in Section 5.

2. CONTEXT AND RELEVANT LITERATURE

Typically, methods for managing congestion can categorized into two main groups: the first one is the closed-loop, and the second one is the open-loop solutions. Open-loop technologies proactively prevent congestion. Congestion is monitored in closed-loop solutions following diagnosis. Congestion detection can be achieved by measuring techniques that monitor how many messages are currently waiting in the queue, the amount of utilization, and the length of time the channel occupies. As discussed in the intro, control approaches to congestion in VANets are grouped into hybrid, CSMA/CA-based, rate-based, scheduling- and prioritizing-based, and power-based approaches [5]. Below, such techniques are discussed.

2.1. Approaches Based on Rate

Rate-based approaches are closed-loop systems that effectively manage network congestion by diagnosing and controlling it. These technologies dynamically reduce the ratio at which packets are transmitted/generated to lessen packet collisions in congested channels.

Sharma et al. [6] proposed a congestion diagnosis model that uses a priority scheme to determine the proportion of transmitted beacon signals. The Tabu-search algorithm is applied to control network congestion. This model allows for

RESEARCH ARTICLE

better management of the network by dynamically adjusting transmission rates.

Jayachandran et al. [7] introduced a strategy that selects a suitable data rate for each BSM transmission based on the current Constant Bit Rate (CBR). Unlike other algorithms that increment data rates in fixed steps, their algorithm dynamically adjusts the data rate according to the current CBR, which accelerates the convergence of channel congestion to the desired level, resulting in reduced packet loss and increased packet delivery. However, achieving high Signal-to-Interference-Noise Ratios (SINRs) within safety range limits remains a challenge for improving data rates in these systems.

While these rate-based approaches provide dynamic congestion control, they often require additional mechanisms to ensure that safety limits (such as SINR) are respected, and they are not always effective in highly dynamic environments with varying mobility.

2.2. Approaches Based on Power

Manage traffic congestion Methods that rely on adjusting the gearbox power to optimize the range. The Power of the gearbox is a critical factor in channel collision, as it is one of the most crucial agents involved. Congestion and channel collision occur when multiple nodes within a comparable communication range vie for channels. Power-based systems are open-loop techniques that alleviate congestion by modifying transmission power and decreasing the channel loads.

Dapaah et al. [8] proposed a model called the Transmission Power-Control Certificate Omission Model. This model balances network packet loss (NPL) and cryptographic packet loss (CPL) to improve vehicle cooperative awareness in high-traffic situations. It effectively controls channel load by diagnosing congestion and applying a congestion control algorithm to optimize the power levels of transmissions.

Chandrasekharan [9] introduced a congestion control strategy using the Markov Decision Process (MDP) and Q-Learning. This algorithm adjusts transmission power levels to minimize congestion while maintaining high vehicle awareness in nearby areas. The model selects the appropriate transmission power based on the current network conditions, helping to balance awareness and bandwidth. Power-based approaches are generally open-loop systems that can efficiently reduce congestion in specific conditions but may face challenges in dynamic environments where the transmission power alone cannot always resolve the congestion problem effectively.

2.3. Approaches Based on CSMA/CA

Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) is a fundamental protocol used in VANETs to control congestion. This protocol works by allocating channel access privileges to each node in the Medium Access Control (MAC) layer, helping to avoid collisions and regulate channel access.

Choe et al. [10] introduced a channel access technique that uses cooperative reinforcement learning (RL) to enable vehicles to coordinate channel access in a decentralized manner. The method improves vehicle-to-vehicle (V2V) safety broadcasts in infrastructure-less, congested VANETs.

Abedi et al. [11] proposed a Tight Synchronised MAC protocol that eliminates the need for a dedicated control channel. The protocol uses shared synchronization and competition mechanisms to create a channel table for each node, which includes information about neighboring nodes and channels. The technique optimizes data transmission through a fair preemptive approach, reducing the switching count during data transfer.

While CSMA/CA-based approaches offer a simple and effective means of managing congestion in VANETs, their effectiveness can be limited in high-density networks, where collisions may still occur due to the contention for channel access.

2.4. Approaches Based on Prioritizing and Scheduling

Congestion control approaches that prioritize messages are designed to ensure that important messages (such as safety-related messages) are transmitted with higher priority and minimal delay, thereby reducing congestion in the network.

Ismail et al. [12] proposed an enhanced congestion control model that uses prioritization and scheduling to manage safety and non-safety messages. The model ensures that safety messages are given higher priority and are transmitted first, while non-safety messages are scheduled for transmission based on available resources. This dynamic scheduling algorithm helps minimize delays in safety message delivery.

Naeimipoor et al. [13] introduced a multi-hop routing protocol that prioritizes urgent messages and guarantees reliable communication for these messages. The protocol uses variables such as the number of neighbors, distance between vehicles, and signal-to-noise ratio (SNR) to select cluster heads and optimize message delivery.

Prioritization and scheduling-based approaches can significantly improve the delivery of critical messages in congested environments. However, they may introduce delays due to the need for rescheduling and the complexity of managing multiple message types in real-time.

2.5. Hybrid Approaches

Hybrid approaches combine multiple congestion control strategies to achieve more effective and efficient management of congestion in VANETs. These approaches typically integrate rate-based, power-based, and scheduling methods to provide a more holistic solution.

Ali et al. [14] proposed a new routing protocol that uses clustering to mitigate congestion and increase the lifespan of Wireless Sensor Networks (WSNs). They combined energy-efficient ultra-scalable ensemble grouping and a flamingo search algorithm for cluster head selection. Rat swarm optimization was used to select routes among cluster heads and base stations.

Patil et al. [15] presented a congestion control system that reduces congestion and increases network throughput. The system uses K-means clustering to determine cluster head indices and applies an adaptive packet rate reduction (APTR) algorithm to control congestion. Ant Colony Optimization (ACO) is employed to enhance throughput and minimize congestion.

Hybrid approaches have the potential to overcome the limitations of individual techniques by combining their strengths. However, they may also introduce additional complexity in implementation and require careful tuning of multiple parameters to achieve optimal performance.

3. PROPOED METHOD

The suggested congestion control approach utilizes roadside units (RSU) located at intersections to manage and prevent congestion effectively. In this area, the probability of congestion is higher due to the accumulation of cars. Articles such as [5] have worked on VANET congestion at intersections and behind traffic lights. Our focus will be on these areas. The suggested approach comprises three sequential stages: 1) congestion detection, 2) notification of vehicles in the congestion area, and 3) data congestion control. The steps of this strategy are explained in detail below.

3.1. Congestion Detection

Based on the amount of data sent, the use level of the channel is measured to assess for recognizing data congestion in drains. When the measured parameter exceeds the pre-described threshold, a section of congestion detection estimates that congestion has happened.

This work's threshold value equals 70% of the receiver's used buffer. This threshold value is considered according to the articles studied, such as [5].

3.2. Collected Data Control

In this phase, messages transmitted between vehicles are buffered and collected in RSUs. In this step, data filtering is done. Each RSU discards low-priority messages received from various automobiles. A random number is generated to determine the priority of letters in the simulation for each packet using a random number generation function based on uniform distribution. Low-priority packets are generated with a one-tenth probability, and high-priority packages have a nine-tenth possibility. All these packets are sent and received before congestion occurs. After congestion occurs, low-priority packets are dropped from the receiver buffer. Apps optimized for VANETs can be categorized into three fundamental techniques:

1) Safety applications (for example, information about road hazards and emergency brake lights) 2) Convenience applications (for example, information about parking availability and congested roads)

3) Commercial applications (for example, information services and map content database downloads) [16], [17].

These applications offer two types of messages for communication in VANETs: safety messages and non-safety messages. Safety messages refer to emergency and beacon messages delivered specifically through the control channel. On the other hand, non-safety messages are signals generated by convenience and commercial applications that are transmitted through service channels [18-20]. Because of the congestion, messages unrelated to safety and have a low priority are discarded, and the network attempts to send high-priority safety messages.

3.3. Congestion control

Communication parameters like rate and transmission range are modified for every transmitter in the congestion control stage. VANET's performance is influenced by content and transmission rate. Messages, particularly safety messages and signals, are typically broadcast with a wide transmission range; therefore, vehicle numbers that obtain such statements rise.

However, when the vehicles' transmission range is larger, a larger area of the surrounding space receives the messages. Naturally, the collision probability increases if the cars in this area have data to send and send it. The rate of transmission impacts channel saturation situations. A high transfer rate develops VANET apps' performance, and this is because most of the info is transmitted to such apps. However, an elevated transmission rate could overwhelm channels and increase the burden on the medium.

Within the suggested approach for setting the sending rate parameter for each sender using optimization approaches to minimize packet loss, the most favourable values of the sending rate are determined and sent to each sender. In continuing the communication with the RSU, the sender sends the messages with the new sending rate.

3.4. Optimization Model

When congestion occurs, the effective solution to reduce the loss of packets due to RSU buffer overflow (in the following

RESEARCH ARTICLE

text is considered as the receiver) and discarding the packets is reducing the sending Rate of vehicles (in the following, regarded as the senders). As the sending Rate of senders decreases, fewer packets are sent in the network. As a result, packets are discarded with less probability (due to receiver buffer overflow). The critical issue in reducing the sending Rate is the rate of reduction. If the sending rate of the senders does not decrease significantly, the problem of the receiver's buffer being full and packet loss will remain. Subsequently, suppose the transmission rate reduction is large, or all transmitters simultaneously reduce the transmission rate. In that case, the transmitters will only transmit a little data even though the receiver's remaining buffer space is empty. Therefore, network bandwidth is wasted due to the low rate of packet sending. To solve this problem and assign the appropriate sending rate (in addition to controlling lost packages, it also prevents the loss of network bandwidth), we model the problem of allocating the proper sending rate as a linear optimization problem to minimize packet loss. One of the references [21] raises the issue of congestion control by optimization strategies in medical sensor networks. The problem is solved according to the considered queue length for each sensor node. In the proposed model of this research, we solved the problem by considering the sending Rate of nodes and how effective each node is in overflowing the receiver's buffer (as the weight of each node involved in congestion). We must consider one basis point to assign a sending rate with minimal packet loss. If a node with a high rate has produced a larger number of packets and continues to work at the same pace, it causes the growth of packet loss in congestion conditions. Therefore, the higher the sending Rate of the node, the more effective it will be in losing packets.

Therefore, to reduce the loss of packets in the event of congestion, the sending Rate of these nodes should be reduced more. We assign a weight. To each node to determine the reduction in the sending Rate of each node. This weight is equal to the production rate ratio depending on the sum of the rates of all network nodes. This parameter indicates the share of sender I in the total number of packets sent in the network. Due to the dependence on the sending rate of the node, this index shows the effectiveness of the sender in losing packets. As shown in equation (1), n is the number of vehicles in the network that can send data.

$$w_i = \frac{Data\_rate_i}{\sum_{j=1}^{n} Data\_rate_j} \quad (1)$$

To determine the new sending rate of the senders, depending on the effective weight of the sender in packet loss, a smaller amount of the receiver's free buffer should be allocated to the said device. The presented model aims to determine these shared values as variables of the optimization model to minimize packet loss. As explained, nodes with higher sending rates have a greater impact on packet loss. Therefore, a smaller share should be allocated to them. Thus, the purpose of the presented model can be formulated as shown in equation (2):

$$\min \sum_{i=1}^{N} w_i . x_i \quad (2)$$

The model aims to minimize the sum of the product of each node's share to the node's weight. That is, nodes with a large weight receive a small amount of the receiver's free buffer. As a result, they reach a further rate reduction. The threshold limit for detecting congestion or receiver buffer overflow was 70%, as in the article [5], due to the non-zero value of the variable. For transmitters with much weight, the minimum value of this variable is equal to one-third of the node's use of the network space. This old network share parameter is called. Also, to realize bandwidth loss and nodes, use all the free lengths of the receiver buffer, and the sum of all shares equals 1. Therefore, the following constraints are considered as optimization model subjects. As shown in equations (3) and (4):

$$\frac{usage_{i,old}}{3} < x_i \quad for\ all\ i \in N \quad (3)$$

$$\sum_{i=1}^{n} x_i = 1 \quad (4)$$

$$0 < x_i < 1$$

The amount of empty buffer is currently one-third of the total pad. The maximum amount of reduction is considered equal to one-third. After determining the share of each node in the remaining space, the rate of each node is defined according to the percentage of each node as shown in equation (5):

$$data\_rate_{i,new} = \frac{x_i}{usage_{i,old}} . data\_rate_{i,old} \quad (5)$$

This model assigns A weight to each node to reduce the cost of sending nodes that effectively overflow the receiver's buffer. The node with more weight receives a smaller share so that the goal of the optimization model's objective function is met, which is used to minimize this sum. Finally, after running the model and determining the new data transmission rate for the automobiles within the congested zone, the RSU located at the intersection sends the new transmission rate to them so that the sender with the latest transmission rate can send its messages. After modelling the model, i.e., in the simulation process, we use the linear problem-solving libraries available in MATLAB software to solve the model. This library solves optimization problems with the standard SIMPLEX method [22]. The detailed steps of the algorithm are outlined in Algorithm 1.

1. Input:
2. Vehicles (V) in the congested area.
3. Roadside Units (RSU) at intersections.
4. Receiver buffer threshold (70%).

RESEARCH ARTICLE

5. Messages with different priorities (safety and non-safety messages).
6. Output:
7. Optimized transmission rate for vehicles.
8. Step 1: Congestion Detection
9. Measure the channel usage by evaluating the data sent between vehicles.
10. If the channel usage exceeds the threshold (70% of the receiver's buffer), congestion is detected.
11. Step 2: Data Control
12. RSU buffers the incoming messages from vehicles.
13. The messages are filtered based on priority:
    a. High-priority safety messages are retained.
    b. Low-priority non-safety messages are discarded with a 10% probability.
14. In case of congestion, low-priority packets are dropped from the receiver buffer.
15. Step 3: Congestion Control
16. The communication parameters (transmission rate and range) for each vehicle are adjusted.
17. The transmission range is adjusted to prevent overloading the channel.
18. An optimization model is used to adjust the transmission rate to minimize packet loss.
19. Step 4: Optimization Model for Transmission Rate Allocation
20. Calculate the weight for each vehicle based on its data rate (Equation 1).
21. The objective of the optimization model is to minimize the sum of the product of each vehicle's weight and its transmission rate, thereby reducing packet loss (Equation 2).
22. Constraints are applied to allocate transmission rates to prevent channel overload (Equation 3 and 4).
23. Transmission rates are updated based on the optimization model.
24. Step 5: Optimization Implementation
25. The optimization problem is solved using the SIMPLEX method in MATLAB software (Equation 5).
26. Step 6: Updating Transmission Rates
27. The RSU sends the optimized transmission rates to the vehicles.
28. The vehicles update their transmission rates based on the new values.

Algorithm 1 Congestion Control in VANET Using RSU

4. SIMULATION PLATFORM

The OPNET simulator was used to simulate VANET networks. The simulation urban mobility (SUMO) module simulates mobility in this network. Like the simulation platform, we applied the simulator of OPNET as the network simulation tool based on events. OPNET lets whole model components' simple implementation. The hierarchical OPNET element is identified in 3 basic layers: a) the model of the node describes basic node blocks and parameters and also presents the interface for components of the network b) the model of the process describes states and state transitions from node model components and summarizes network component manner. In addition, C++/C code monitors every process model state and can be customized. OPNET technique APIs are applied to improve and support communication mechanisms like traffic, packets, and queues. c) The network model contains a set of nodes and describes relations among them. OPNET Modeler allows both random and trajectory mobility. The last element is set, applying the way file to each node. The technique presents situations for more complicated node movements. Unfortunately, relations among nodes are not taken, so realistic mobility is restricted. To our knowledge, no tool exists for OPNET Modeler that could carry out the process of simulation applying the realistic mobility model [23]. Figure 1 shows the three-layer model in OPNET.

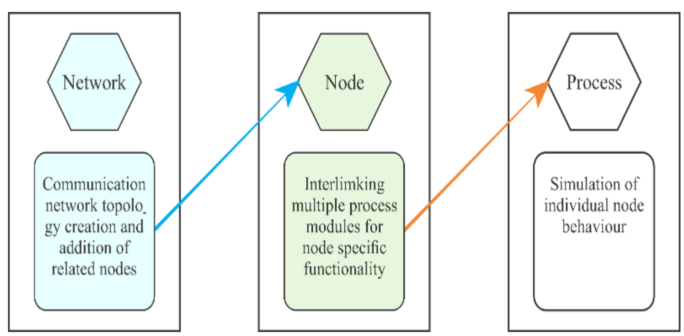

Figure 1 Three-Layer Model in OPNET

4.1. Implementation with MATLAB

MATLAB software is used to implement the optimization problem, and it can communicate with the OPNET simulator. MATLAB code is called after setting OPNET parameters to identify MATLAB system libraries. After executing the desired code, the results are returned to OPNET. According to these results, OPNET adjusts the network parameters and continues the simulation. More details about establishing this connection are provided in reference [24]. After the simulation process in OPNET in the existing scenario, the traffic is generated and flows in the network. At the moment of congestion, an optimization problem is created by RSU, and the MATLAB software is called. By performing calculations and solving the model in MATLAB, the answers are returned to the OPNET simulator.

4.2. Topology and Parameters

To evaluate the study, we compare the proposed approach to the CSMA/CA [10] method, a standard congestion control method used in wireless networks. We use network efficiency parameters, including packet sending delay, packet loss rate, network throughput, and other parameters for analysis and evaluation. How to use MATLAB to perform simulation is presented in Figure 2. The motion path and speed of vehicles are specified in this topology. As these vehicles approach the RSU, they are placed in the congestion area. By determining the appropriate transmission rate according to the proposed solution, RSU performs congestion control. The simulation parameters are presented in Table 1.

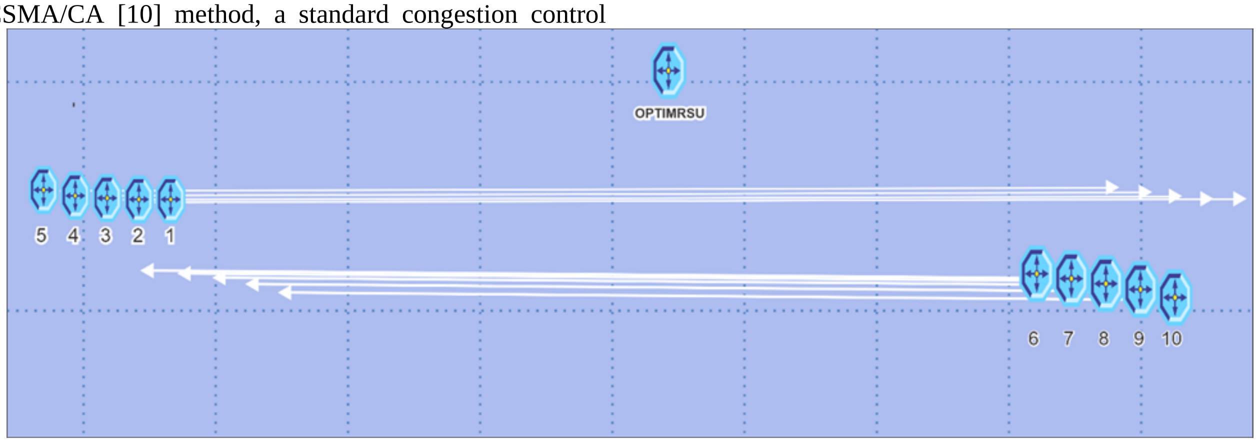

Figure 2 Proposed Topology

Table 1 Simulation Parameters

Simulation Parameters	
Sender number	10
Initial sending rate	2, 5.5, 11
Packet length	1024
Packet type	Safety with priority one and non-safety with priority 0
Receiver buffer rate	256000

4.3. Performance Evaluation

The subsequent part assesses and examines the effectiveness of the proposed approach in contrast to the CSMA/CA method.

4.3.1. Packet Loss

As stated in the previous sections, the main objective of the proposed method was to reduce packet loss. The proposed method appropriately reduces vehicles' transmission rate in the congestion area. All vehicles then send data to the RSU at set rates. Figure 3 shows that congestion is formed after senders send a portion of data in the network. In the CSMA/CA method, nodes continue to transmit. However, the proposed method reduces the amount of data sent by reducing the sending Rate of the senders. It minimizes the loss of packets due to the overflow of the receiver's buffer. The number of discarded boxes is reduced due to buffer overflow, and the quality of service is improved.

The effect of reducing the data transmission rate by the proposed method and the CSMA/CA method on the amount of received data, the amount of sent data, and the amount of discarded data is shown in Figure 4. As stated in the previous section, low-priority messages are not considered during congestion to reduce the receiver's workload in the proposed method. In the CSMA/CA method, the sending Rate of the senders continues to rise due to the lack of reduction in the sending rate. As seen in Figure 4, the amount of data received is uniform, and the data sent more than the receiver's ability to receive is discarded.

RESEARCH ARTICLE

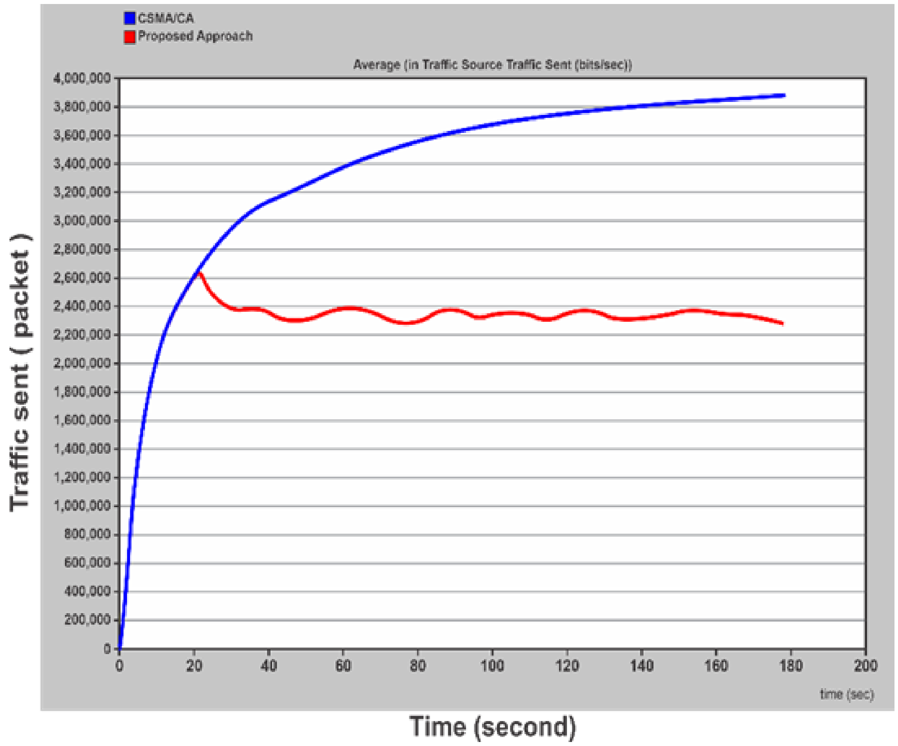

Figure 3 Comparison of the Amount of Data Sent in the CSMA/CA Method and the Proposed Method

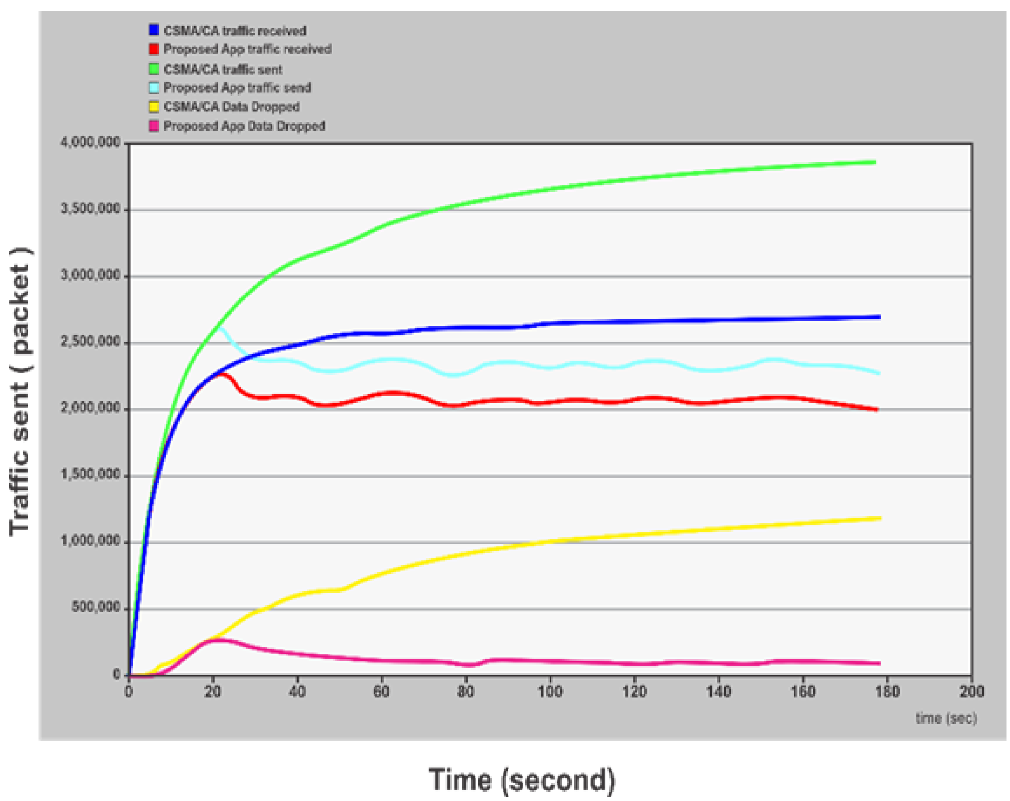

Figure 4 The Amount of Data Sent, Received Data, and Discarded Data in the Proposed Method and the CSMA/CA Method

RESEARCH ARTICLE

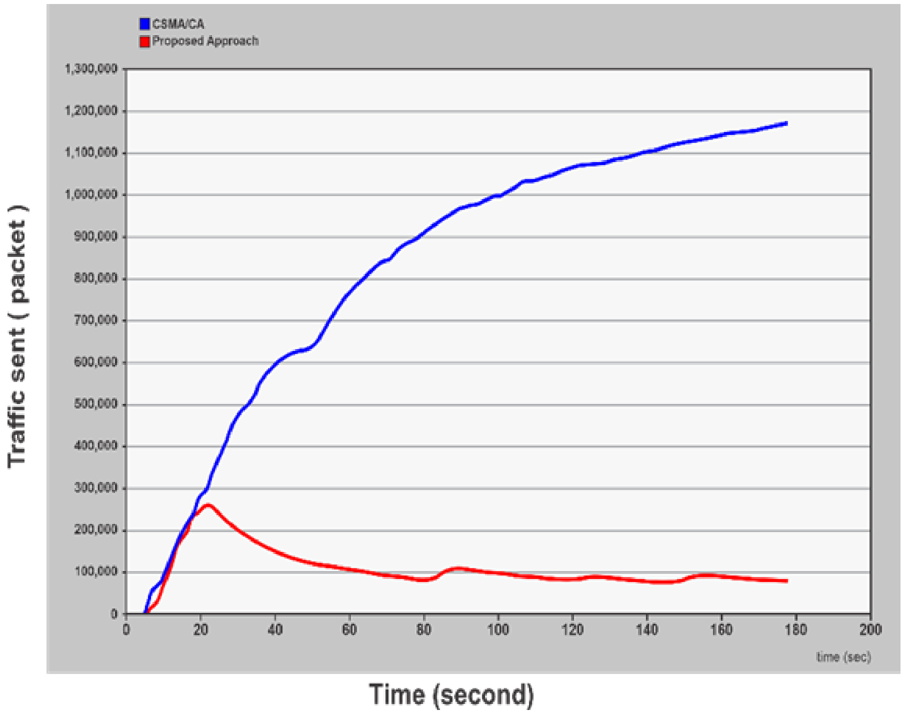

Figure 5 Comparison of Packet Loss in the CSMA/CA Method and the Proposed Method

Figure 5 compares the discarded data in the CSMA/CA and proposed methods. As shown in the previous figures, the proposed method can reduce the loss of data packets. In this way, the main goal of the proposed research, which is to minimize packet loss and improve the quality of service provided in network communications, has been achieved. By reducing packet loss, the quality of the provided service is improved. Reducing the sending Rate of senders (vehicles) should not be such that all nodes stop sending data at once and network bandwidth is wasted. Subsequently, the reduction rate should not be so low that the problem of overflowing the receiver's buffer or RSU remains when the packets are discarded, and the amount of packet loss is not reduced. By considering these two goals, the proposed solution can determine the sending Rate of nodes and achieve the goal of reducing packet loss and improving the quality of the service provided.

4.3.2. Throughput

One of the important parameters in evaluating network efficiency is network traffic throughput. In this section, we examine the effect of the proposed method on this parameter. Despite the decrease in the sending Rate of the senders in the network, the network's throughput is expected to decrease. However, considering the receiver's capacity, reducing the transmission rate leads to the reduction of discarded data. It also prevents the receiver buffer from being empty. Therefore, compared to the CSMA/CA method, the network throughput does not decrease significantly. Figure 6 compares the throughput in two CSMA/CA methods and the proposed method.

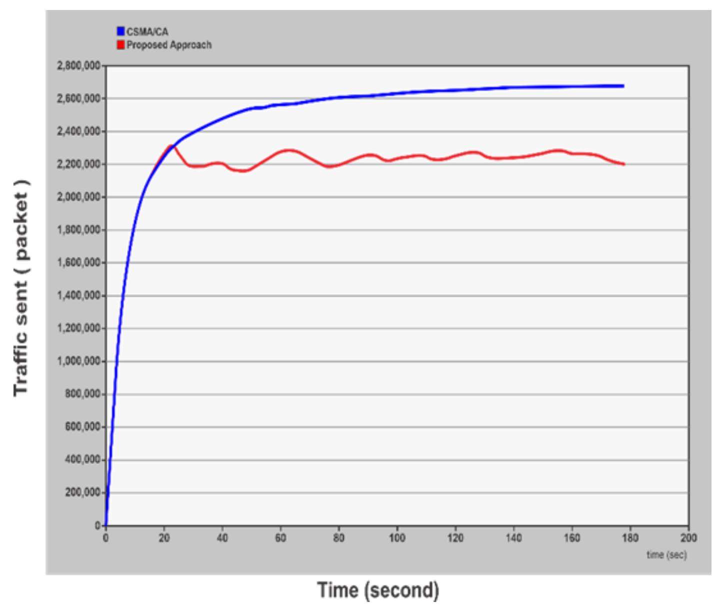

Figure 6 Comparison of Throughput in the CSMA/CA Method and the Proposed Method

4.3.3. Latency

We evaluate the data transmission latency to check the proposed method regarding other important parameters in service quality. Due to the decrease in network traffic due to the reduction of the sending Rate of senders, the network load decreases. By reducing the network load, messages received by the receiver will wait less time in the receiver's buffer queue for processing. In this way, the proposed method, in addition to reducing packet loss, has also positively affected the latency of transmitted data. The comparison of this parameter is presented in Figure 7.

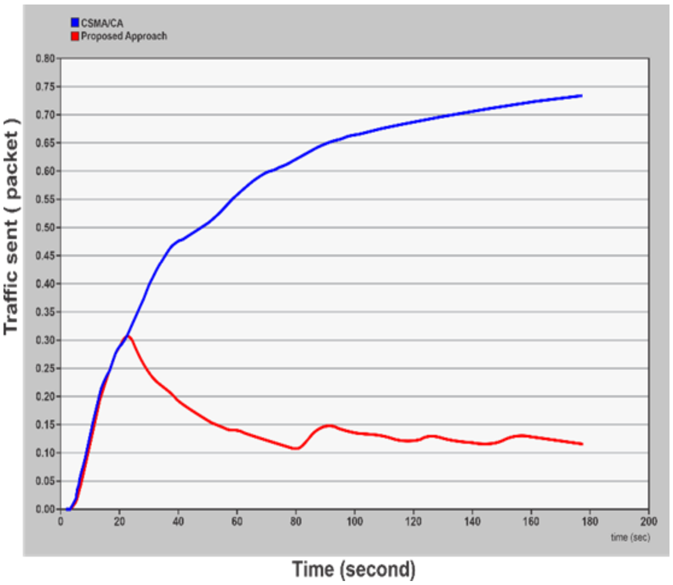

Figure 7 Comparison of Latency in the CSMA/CA Method and the Proposed Method

In addition to losing packets and its negative impact on the quality of service provided in the network, receiving data with latency is also considered one of the challenges of service quality. By reducing the sending Rate of senders and considering the buffer of the receiver, the amount of utility of the remaining buffer space is managed so that the amount of discarded data and the data latency in the buffer are reduced.

4.4. Discussion

The proposed method shows superior performance over the CSMA/CA approach in terms of packet loss, throughput, and latency. By reducing the transmission rate during congestion, the method effectively balances network traffic, preventing buffer overflow and minimizing packet loss. The results presented in Figures 3, 4, 5, and 6 demonstrate that the proposed approach outperforms the CSMA/CA method in maintaining QoS and enhancing network stability.

In terms of packet loss, the proposed method stands out by significantly reducing the number of discarded packets, which is a critical issue in congested vehicular networks. Moreover, the throughput remains largely unaffected despite a reduction in transmission rates, highlighting the method's efficiency in optimizing data transmission without sacrificing performance. Regarding latency, the proposed method manages buffer space effectively, resulting in quicker data delivery and lower queuing times.

The significant improvements achieved by the proposed method can be attributed to the dynamic adjustment of transmission rates in real-time, considering both congestion levels and receiver buffer capacities. This intelligent rate control mechanism not only prevents data loss but also optimizes throughput and latency, making it a robust solution for vehicular networks.

5. CONCLUSION

The purpose behind using the optimization problem-solving, congestion is controlled by minimizing the packet loss rate (the number of lost packets). Indeed, after modelling the congestion and solving the problem, the data transmission rate is determined to minimize packet loss. To evaluate the efficiency of the proposed protocol, the mentioned solution has been compared with conventional data congestion control methods in networks such as CSMA/CA in terms of network service quality parameters, including the number of lost packets, throughput, and delay. The proposed method can reduce the amount of data sent by reducing the sending Rate of the senders. In the proposed way, the bandwidth of the network should be reduced. However, the proposed method provides reduction conditions by considering the receiver capacity. Reducing the transmission rate lowers the amount of discarded data. The receiver buffer is also prevented from being empty. Therefore, the network throughput increases little compared to the CSMA/CA method. In the proposed method, the amount of network load is reduced due to the reduction of network traffic and the reduction of the sending Rate of senders. By lowering the network load, the messages the receiver receives will wait less to leave the receiver's buffer queue and be processed. In addition to its effectiveness in reducing packet loss, the proposed method reduces the delay of data sent. Finally, according to the simulation results, it can be concluded that the proposed method performs better than the CSMA/CA method.

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RESEARCH ARTICLE

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