Article

Traffic Flow Management of Autonomous Vehicles Using Platooning and Collision Avoidance Strategies

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Abstract: Connected Autonomous Vehicles (AVs) promise innovative solutions for traffic flow management, especially for congestion mitigation. Vehicle-to-Vehicle (V2V) communication depends on wireless technology where vehicles can communicate with each other about obstacles and make cooperative strategies to avoid these obstacles. Vehicle-to-Infrastructure (V2I) also helps vehicles to make use of infrastructural components to navigate through different paths. This paper proposes an approach based on swarm intelligence for the formation and evolution of platoons to maintain traffic flow during congestion and collision avoidance practices using V2V and V2I communications. In this paper, we present a two level approach to improve traffic flow of AVs. At the first level, we reduce the congestion by forming platoons and study how platooning helps vehicles deal with congestion or obstacles in uncertain situations. We performed experiments based on different challenging scenarios during the platoon's formation and evolution. At the second level, we incorporate a collision avoidance mechanism using V2V and V2I infrastructures. We used SUMO, Omnet++ with veins for simulations. The results show significant improvement in performance in maintaining traffic flow.

Keywords: platooning; autonomous vehicles; traffic flow management; collision avoidance

1. Introduction

Disruptive innovation in the automotive industry led by the emergence of advanced Autonomous Vehicles (AVs) and vehicular networks has given rise to novel intelligent transportation mechanisms. IoT-based systems underpinned by real-time data gathered through sensors, deployed within vehicles and in the environment have escalated progress. Such data can be interpreted to manage traffic, identify appropriate navigation paths, improve efficiency, and enhance mobility whilst conforming to traffic management policies [1,2]. However, significant progress is still required to deal with dynamically changing conditions in unanticipated circumstances. The environment does not work as predicted and may cause congestion or a backlash in the vehicular system. Traffic congestion causes adverse effects on traffic flow by substantially decreasing the vehicle's navigation, increasing trip times and queue lengths. Maintaining traffic flow through variety of classical techniques [3,4] has been significant. Considering the paradigm shift towards AVs, there is a dire need to look for new long-term solutions. These solutions may focus on reducing the congestion and travel times while improving the road capacity for AVs. The AVs penetration rate can be measured as the ratio of AVs on the specific network to the total number of all vehicles in a certain period. The AVs penetration rate in the market is predicted to increase from 24% to 87% by 2045 [5]. The performance of different approaches is greatly dependent on the penetration rate of AVs on the roads [6].

While traffic congestion leads to intense degradation on a freeway road network, efficient throughput on urban roads can be maintained via suitable strategies and control measures [7]. For instance, collision avoidance strategies can result in minimum road blockages and traffic jams caused by accidents, thus enabling the system to perform efficiently under varying conditions [8]. V2V and V2I technologies consist of a wireless network used in AVs to deal with escalating problems, reduce congestion, and enable efficient flow management of vehicles. V2V communications using platooning is a robust methodology to minimize traffic congestion and increase lane capacity by reducing gaps and allowing coupling between vehicles [9]. In platooning, groups of interacting vehicles can follow standard rules when sudden obstacles or traffic demands exceed the infrastructural capacity. Due to the overcapacity of the road networks, even the Advanced Traffic Information Systems (ATIS) [10] may have limited use of GPS data. Platooning is a viable approach, making vehicles closer to each other and eliminating the constant stop-and-go that would help avoid wasting time and energy. AVs could have the best possible implementation of platoons because they are free from the restrictions related to human behavior, such as driver's behavior, reaction time, and coordination. IVC (Inter-Vehicle Communication)-enabled AVs can behave in a synchronized manner, avoiding traffic disturbances, have strong coordination, and require minimum reaction time [11].

Recent advances in communication technology can complement the vehicle-mounted equipment [12] such as camera, radar, laser, etc. This makes a vehicle aware of the complex environment that is beyond the line of sight. In IVC-enabled vehicle's perception, the range of surrounding environment and traffic can be expanded from the dimension of space and time, which is why the vehicle can take multi-information fusion decisions [13]. In AVs, the usefulness of platooning on urban road networks is enhanced with the improvement of advanced communication technologies. These technologies include Dedicated Short-Range Communications (DSRC) [14,15], which is a specifically designed communication channel for the automotive industry; Cooperative Adaptive Cruise Control (CACC) [16], which is the extended version of ACC; Long Term Evolution Advanced (LTE-Advanced) [17], which used as the mobile communication; and Personal Rapid Transit (PRT) [18], which is specially designed vehicular technology and uses special guide-ways for operation. Moreover, since the vehicles in platoons are very close to each other, the air drag is minimal because vehicles are operating in closed proximity, and the energy consumption is also reduced.

Analyzing the safety criteria and finding the safe sets under scenarios such as collisions or accidents is also a crucial aspect to be considered for AVs. Current collision avoidance systems such as ACC use radar information for adjusting itself, or communication with breaking signals is used where delays or system failure could cause serious damages [19]. For rigorous guarantees, the combination of V2V and V2I could be beneficial for managing traffic flow problems. To achieve this purpose, in this paper, we propose a strategy to cope with the traffic flow problems of AVs at two levels. At the first level, we propose algorithms of platoon formation and discuss special cases, and, at the second level, we cope with collisions. The scientific contribution of this research can be summarized as follows:

- At the first stage, our algorithm resolves congestion on the intersection and creates platoons of vehicles and then reroutes those platoons to alternate paths to minimize the traffic jams. The algorithm also reduces the intra-platoon spacing while increasing the lane capacity.
- The proposed algorithm also resolves the congestion for the traffic coming behind the intersection by notifying them in advance about the upcoming congestion and rerouting them to alternate routes for the sake of congestion avoidance.
- We propose strategies to mitigate exceptions that occur during platoon's navigation, i.e., leader vehicle failure, obstruction within platoons, multiple platoons come together, etc.
- At the second stage, we implement collision avoidance strategies using V2V and V2I and demonstrate considerable performance increase.

The novelty of the proposed approach lies within its strategic pipeline which is a unique combination of different algorithms (i.e., platooning, rerouting, and collision avoidance) organized in such a way that it improves the overall traffic flow management for autonomous vehicles. The pivotal concept of the approach is that AVs can be managed better and traffic flow can be improved efficiently and effectively by applying rules on platoons of vehicles rather than managing vehicles one by one. These rules are defined based on the physical properties of the vehicles and as per dynamically changing situations. Simulations were performed by coupling the traffic simulator SUMO with network simulators VEINS and Omnet++. Simulation results show improved performance when employing the proposed approach.

The remainder of the paper is organized as follows. Section 2 presents the related work. Section 3 defines the traffic flow modeling. In Section 4, the proposed approach is described in detail. Section 5 overviews the experimental setup used in this work. The results are discussed in Section 6. Section 7 concludes the paper.

2. Related Work

This research constitutes several fields of study such as autonomous vehicles, swarm intelligence, communications, etc. Much research is published in this area in recent years. Many researchers, technology companies, and automakers have implemented various solutions to improve safety and capacity in AVs, such as ACC [20] including no communication functions and CACC [21] including communication functions. Platooning using CACC is of particular interest because of its ability to improve capacity in a significant manner. In [9], strategies for intra-platoon's safe and stable operations and information management are presented. Different algorithms for mitigating communication delays are proposed. The authors reported that platoon string stability depends on anticipatory information coming from both vehicles' leader and followers. The simulation results using Matlab/Simulink showed platoons' stable behavior, and communication delays were reduced under several scenarios.

IVC-enabled vehicles play a major role in reducing congestion and maintaining a smooth flow of traffic by exchanging data among them. In [11], the authors used a platooning approach to increase roads' capacity and avoid constant stop-and-go. Studies of new models with platooning capabilities are discussed. The authors used SUMO for simulation results. The study presented in [22] shows strategies for platoon formation and evolution of AVs in free-flow. According to the concept, some rules are defined, and all vehicles in platoons follow those rules to move together without collisions. A spring–mass-damper -system is used to define these rules. The results show that flow with critical damping and maximum relationship between the constant spring causes the most efficient platooning. However, vehicles' freedom to change lanes in low-flow states can be achieved by the cubic relationship coupled with overdamping. In [23], the authors studied Visible Light Communication (VLC) technology for AV platoons. They proposed a simple out-door VLC prototype with low-latency and low-cost used as a tail-lighting component in vehicles. They used the Simulink system for their experiments. Experiment results show that, if we narrow the Field-Of-View (FOV) of the transmitter and on the receiver side, if we use the proper optical filter, it will make the VLC system more resilient against ambient noises by extending its communication range. It improves the performance of AV platoons.

Platooning strategies based on Model Predictive Control (MPC) have been used for AVs by enabling cooperation among vehicles to improve their performance. In [24], the authors proposed a cooperative control strategy based on MPC-enabled platooning. The study suggests an embedded optimal control solution algorithm to enhance the performance of platoons. Two approaches are developed to deploy the proposed cooperative control strategy; the first one is the Deployable-MPC (DMPC) approach. Before each sampling time, a time reservation is made so that the optimal control decisions are estimated. The following vehicles execute these decisions to control their behavior at each time instant. The problem with DMPC is that the calculated optimal control decisions might deviate

from the ideal MPC strategy due to prediction error. The second strategy is DMPC with First-Order Approximation (DMPC-FOA) that captures the impacts of prediction error due to optimal decisions. The implementation of platooning and difficulties associated with it is discussed in [25]. The authors proposed an Artificial Intelligence (AI)-based physical platform using miniature cars to form platoons. They named this AI-based platform ALIVE (Autonomous Learning Intelligent Vehicles Engineering). ALIVE is a low-cost, easy to use, and energy-efficient platform, where V2I-based data handling is used for platooning. The authors also compared ALIVE results with real conditions and showed the effectiveness of their research.

An architecture for tight multi-lanes platoons of AVs travelling on public roads is presented in [26]. Various geometrical configurations are used to form platoons with different configurations. These platoons can be on one or more lanes, reshape themselves, and make adjustments according to the situation. The proposed architecture has two components: the first one is an online hierarchical control, while the second one is an offline motion planner. For the formation and reconfiguration of platoons in motion planner, an optimization-based scheme is used in tight spaces. The collision-free trajectories are planed by this scheme which is feasible, smooth and for platoon's vehicles. The online system has three components: a follower, a TOS (Traffic Operation System), and a decision-maker. Simulation results based on case studies show the effectiveness of the approach. Lane changing operations in vehicles are complex because the vehicle has to split from platoon while changing lane. The study presented in [27] proposed a lane change strategy that allows the vehicle to directly change the lane and join another platoon without splitting up any platoon. Longitudinal positions of two platoons are aligned and locked in adjacent lanes. The results show that, in space-time, there is approximately 4342 ms improvement in road utilization. In [28], the authors proposed a Eco-CACC system that is using V2V technology to reduce pollutant emissions and energy consumption in platooning. A full set of protocols are developed for environment-friendly CACC, including a gap regulation platoon's cruising, sequence determination, splitting/merging platoons, and gap opening/closing. Simulation results of changing scenarios using MATLAB/Simulink show 17% emission reduction and 2% energy saving during platoon joining procedures. In [29], the authors discussed the stability of platooning of vehicles and showed how available policies and information of platoons affect the strength. The authors demonstrated the existing strategies are not sufficient for obstacle avoidance in platoons. They proposed a new method for the formation of platooning and avoid collisions. In [30], collision avoidance is achieved by a broadcast mechanism that uses dedicated short-range communication-based packet forwarding. The authors explained in detail that broadcasting is more beneficial than unicast routing in safety-critical systems. The authors proposed an implicit acknowledgement method for improving packet delivery rate and developed a simulator named inventSim. Two main approaches for communication are DSRC by IEEE that supports vehicular ad-hoc WLAN technologies standardized as IEEE 802.11p and act as basis for European standard ETSI ITS-G5, and Cellular-based V2X (C-V2X), a proposal by the 3GPP, based on Long-Term Evolution (LTE), also known as LTE-V2X [31]. Recently, New Radio (NR) vehicle-to-everything has been specified in rel-16 standard of 3GPP based on 5G technology [32]. The release-16 specifies the 5G technology in the use cases that requires more stringent requirements and in sophisticated applications such as advanced driving, platooning etc. In [33], the authors studied V2V communications using different wireless technologies and optimized high-density truck platooning performance. They compared two technologies: 3GPP Cellular-V2X (C-V2X), and IEEE 802.11p. The C-V2X technology is based on 14 release of LTE standard and uses two communication modes: the base-station scheduled named Mode 3 and autonomously scheduled named Mode 4. The results show that c-V2X performed better according to their scenarios. In [34], the authors discussed the factors and design choices for the platooning application's performance based on emerging technology cellular-V2X. They considered the 3GPP's scheduled mode assisted by the eNodeB for communication. The article focuses on the resource management algorithm

using 3GPP, as members of platoons needed radio resources on a per-packet basis. The simulation results provide good insights into the latency performance of the exchange of data, reliability, and latency reduction in the update cycle. In [35], the authors proposed an algorithm for obstacle avoidance based on two layers. The global path optimization layer gives information about the obstacles from sensors using a clustering technique. The local path optimization is done using global optimization and a model predictive control structure obtained through multi-phase optimal structure and vehicle constraints. Simulation results show that the proposed approach is very energy efficient. In [36], a cluster-based architecture using LTE and Wi-Fi is proposed. The cluster formation is done using peer to peer Wi-Fi channels, while Cooperative Awareness Messages are transmitted using LTE channels. The authors also proposed a clustering algorithm for collision avoidance on intersections and a channel allocation algorithm to reduce the Wi-Fi channel interference between clusters.

Our approach considers various aspects from some of these approaches and presents a more holistic solution to the navigation of AVs through platooning and their obstacle avoidance.

3. Traffic Flow Modeling for Platoon Navigation

Traffic bottlenecks may occur due to the nonlinear and complex behavior of the vehicles. Each vehicle has individual behavior that depends on the driver operating the vehicle. The development of autonomous vehicles has ironically reduced the errors caused by the driver's behavior [37]. Advanced technologies used in AVs allow vehicle interactions following not only mechanics' laws but also V2I and V2V communications. The traffic stream could be visualized by analyzing the vehicles' speed, vehicles' density, and traffic flow described in detail in [38]. The trajectory line of each vehicle shows the path or lane each vehicle is moving in. In Platooning, groups of vehicles operate together as a single unit, and each platoon has a leader vehicle that leads the entire platoon. We have to define some basic maneuvers that are required for vehicles in platoons to move. The distance that AV platoons cover in unit time is the speed of the platoon. As in platoons, vehicles are moving in groups, we use average mean speed instead of measuring each vehicle's speed. Average mean speed could be estimated using the arithmetic mean and harmonic mean and could be classified into the category of time and space [39]. The arithmetic mean speed of the vehicles, sometimes called time mean speed, could be measured as:

$$s_{tm} = \left(\frac{1}{n}\right) \sum_{i=1}^{n} s_i \tag{1}$$

where s_i is the speed of ith vehicle of total n vehicles that are passing through a certain point. Loop detectors are used to measure the time-mean speed spread over a reference area by identifying vehicles and their speed. The arithmetic mean speed of all passing through a road segment at specific time t could be defined as:

$$s_{sm} = \left(\frac{1}{n(t)}\right) \sum_{i=1}^{n(t)} s_i \tag{2}$$

where $n(t)$ represents the sum of all vehicles passing through the road segment at time t. The harmonic mean speed is used to measure the average speed of whole road segment at fixed time interval neglecting accelerations. The data for space mean speed is in the form of images taken from cameras embedded on the infrastructure using V2I.

$$s_{hm} = \left(\left(\frac{1}{n}\right) \sum_{i=1}^{n} \left(\frac{1}{s_i}\right)\right)^{-1} \tag{3}$$

Similarly, the road segment's AVs per unit length represents the density d of vehicles. In traffic flow management, mainly two types of densities are important: the first one is

called critical density d_c, which is the free flow's maximum density, while the second one is called jam density d_j, which is the jam's maximum density. The spacing between the vehicles is the inverse of the density $d = 1/s$. The average spacing between n vehicles is thus the inverse of the density of the roadway's length L_r at time t_1.

$$D(L_r, t_1) = \frac{n}{L_r} = \frac{1}{\bar{s}(t_1)} \tag{4}$$

The density of the region M_1 can be evaluated as:

$$D(M_1) = \frac{n}{L_r} = \frac{n\, dt}{L_r\, dt} = \frac{tt}{|M_1|} \tag{5}$$

Here, tt represents the total time travelled in the region M_1. The above equation is Edie's definition of density [40]. The number of AVs passing from any point in unit time represents the flow f of traffic. The headway h_w is the elapsed time between the ith and (i + 1)th vehicle passing through the reference point and is typically inverse of flow. Headway remains constant in congestion and approaches infinity as a traffic jam forms. Basically, flow is $f = d.s$ where d is density and s is speed, and $d = 1/h_w$ where h_w is the headway. Thus, we can say that, during a time interval (T), at a fixed point (y_1), the flow f passing through that point is equal to the n vehicle's average headway.

$$f(T, y_1) = \frac{n}{T} = \frac{1}{\bar{h_w}(y_1)} \tag{6}$$

In region M_2, flow can be evaluated as

$$f(M_2) = \frac{n}{T} = \frac{n\, dx}{T\, dx} = \frac{td}{|M_2|} \tag{7}$$

The total distance travelled by the vehicle is represented as td. The density, flow, and speed are used for the congestion detection that could cause traffic jams. Traffic jams mostly depend on the upstream density, traffic flow, and may have variations in propagation length. The congestion can be calculated as a delay in vehicles navigation from one point to another or the long queue lengths. If there is no delay while travelling between two points, then traffic flow is smooth, but, if there is a delay, it shows the congestion in that area. The average delay can be measured as

$$Delay(avg) = \frac{Sum\ of\ total\ delay\ by\ n\ vehicles}{total\ vehicles\ that\ are\ delayed} = \frac{TD}{n} \tag{8}$$

If the leader vehicle sees congestion in the road, then avoiding that congestion will cause the whole platoon to either avoid or be alerted to its route in the congestion. Various scenarios regarding platooning and collision avoidance are discussed below.

4. Proposed Approach and Implementation Strategy

Autonomous vehicles have excellent potential capabilities to deal with urban traffic congestion and improve traffic safety, efficiency, and stability. Traffic flow management of AVs needs to develop such strategies and techniques to help vehicles handle unwanted situations. Dealing with obstacles is very important for AVs, and future management systems should be equipped with all the instruments needed to manage traffic in this regard. Algorithms based on V2V and V2I interactions can be utilized to deal with the obstacles efficiently. Developing solutions for typical routine tasks on roads could become problematic and needs serious consideration when dealing with vehicles with no human driver present. There is a great practical significance of these solutions while making the transition from normal to autonomous systems. For this purpose, we develop a two-phase approach for congestion management and collision avoidance to manage the flow of traffic.

As shown in Figure 1, our approach manages traffic flow on two levels. On the first level, congestion management uses vehicles platooning and rerouting platoons to alternate paths to avoid traffic jams. Density, speed, and flow are all interrelated terms, as flow (f) is the product of density (d) and speed (s). The traffic flow becomes zero when any one or both terms becomes zero, and, similarly, an optimized traffic flow could be obtained at some critical combinations of density and speed. Traffic jams occur when speeds are very low and densities are very high. In such situations, routing vehicles to alternate routes could improve the traffic conditions and reduce the traffic densities to the normal flow conditions. Flow could be measured by using Equation (7). Usually, traffic congestion occurs at intersections and causes longer queues and delays for the vehicles at the intersection and the traffic coming behind the intersection is also delayed due to this congestion. In our approach, we use platooning for the navigation of vehicles through traffic congestion. Vehicles in the platoon are rerouted to alternate paths at the intersection when density becomes high enough to cause traffic jams. The vehicles coming behind the intersection that have not yet entered the traffic jams are rerouted to alternate paths to avoid further congestion. The detectors identify the jams. We set a threshold limit according to the lane capacity. When vehicles enter the specific region, the critical density d_c kicks off, whereas the jam density d_j starts when vehicles entering the region reach the threshold limit. The platoons of vehicles are then rerouted towards alternate paths to reduce vehicle density. The platoons of vehicles coming behind the intersection get the notification about the delay of vehicles at the intersection and they take alternate paths before entering the congested regions. We implemented multiple scenarios for exception handling regarding the platoons participating in the traffic flow management. On the second level of our approach, we propose and implement collision avoidance strategies using V2V and V2I interactions and demonstrate their significance. We purposefully designed scenarios where collisions may occur and generated obstacles across the road network. if any vehicle collides with the obstacle, vehicles immediately behind the crashing vehicle receive a warning message. This warning notifies the vehicles about the crash ahead and, therefore, they slow down. All other vehicles in the platoons in that specific region receive an alert about the collision's location. The lane on which collision has occurred is marked as a hazard lane and vehicles that are not on the hazard lane are considered safe, while vehicles on the hazard lane actively try to change the lane. If the whole road segment is blocked due to the collision the whole route is marked as a hazard route and vehicles are rerouted to the alternate routes. V2V and V2I communication such as detectors and messages between vehicles are used to avoid collisions. The results in Section 6 show the effectiveness of our methods.
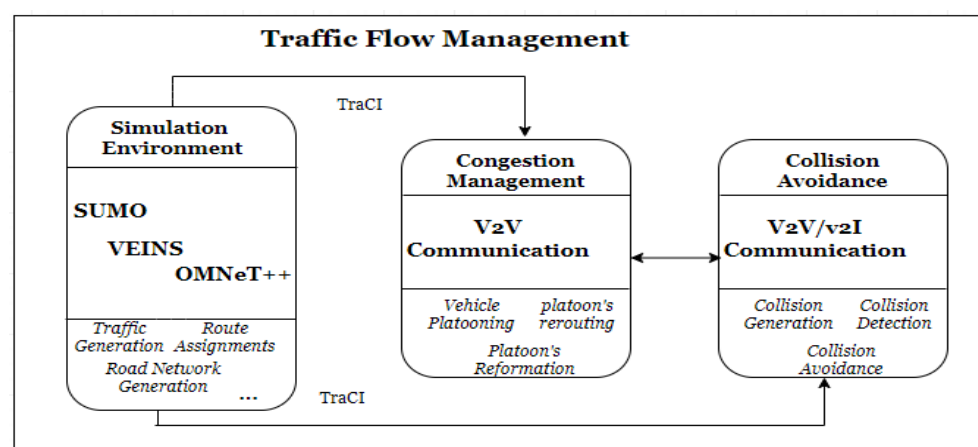

Figure 1. Proposed approach: traffic flow management by congestion management and collision avoidance using simulation environment.

4.1. Congestion Management Using Platooning

AV platooning helps increase lane capacity, reduce congestion, improve traffic flow, minimize fuel consumption, improve passenger comfort, and increase safety. These benefits could be achieved by improving the vehicle's platooning strategies: improving lateral and maneuver coordination and automating longitudinal control. Maneuver coordination is a function that is responsible for maneuvers that include the formation of platoons, splitting of platoons, coordination of lane changes, and merging of traffic flows [41]. In this paper, we investigate the sub-part of maneuver coordination: the process of organizing vehicles in platoons during congestion and collision avoidance using platooning and infrastructural components.

In Figure 2, a general representation of vehicles platoons is shown. The spacing between vehicles, also called intra-spacing, is represented as aS, and the inter-spacing platoons are shown as pS. The length of each vehicle is aL, whereas spatial headway aH equals the sum of vehicle length and spacing between vehicles. There is V2V communication between vehicles and V2I communication between vehicles and infrastructural components.
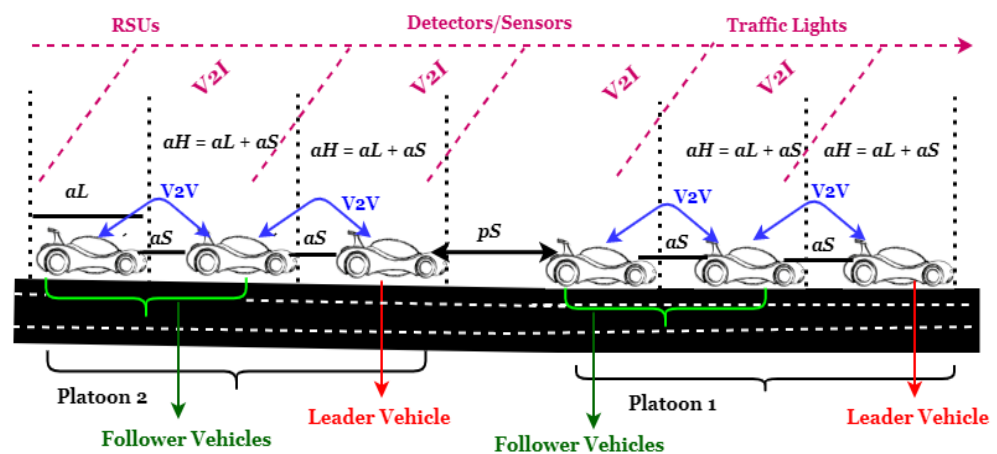

Figure 2. Platooning of vehicles with leader and follower vehicles using Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication.

4.1.1. Platoon Formation

In this approach, we use some assumptions including that all vehicles on the road are AVs, there are no compatibility issues in the vehicles, and the communication between vehicles is reliable. In simulation settings, 60% of vehicles have the same origin and destination, while 40% of vehicles have different destinations but share the same route until their destination arrives. Vehicle route distribution is done using the DUA router used in SUMO. Based on Origin– Destination (O-D) matrix, vehicle platoons are formed with many other configurations described in Algorithm 1 and Table 1. When congestion occurs, these platoons are re-routed to alternate paths minimizing the congestion and increasing the flow of traffic on the roads. The steps included in platoon creation are given as:

- Obtain the O-D matrix and the routes of all vehicles. In the current study, we assume that 60% of vehicles have the same O-D while the remaining 40% share the same route with different destinations.
- The vehicles sharing the same O-D or same route are assigned as members of the platoon. In the present study, we assume that all vehicles are fully autonomous, equipped, and adjacent vehicles on different lanes will change to a common lane during the platoon's formation.
- Retrieve the list of all vehicles in the current platoon.
- Generate and return a unique ID for the platoon and get the lane of the current platoon.
- Set the kinematic status such as position, speed, velocity, acceleration, etc.

- Obtain the length of each vehicle and total length of the platoon by taking the distance between the leader vehicle's front bumper and the back bumper of the last vehicle in that platoon.
- Set other parameters such as max platoon size (Including the maximum number of vehicles allowed in the current platoon), inter-platoon spacing (current spacing between vehicles), and the intra-platoon spacing (spacing between two platoons). These parameters help to set operational strategies for platoons in dynamic traffic conditions.
- When a new vehicle wants to join the current platoons, then the "Eligible for merge" criterion is satisfied from its route file, the vehicle is added to the current platoon, and an updated size of the platoon is obtained.
- When the number of vehicles in current platoons is increased from threshold limit (set with other parameters, eight vehicles in our case), then the platoon is split into two or more platoons.
- If two platoons have the same O-D or sub-route to specific O-D and the total number of vehicles of both platoons is less than the threshold size of a platoon, then two platoons could be merged as one.
- If a platoon is no longer active in the scenario, then disband the platoon, and, when all vehicles of current platoons reached their destinations, mark the platoon as dead.

Table 1. Environment configuration.

Simulation Parameters	
Parameter	**Value**
Simulation Tools	SUMO, Veins, OMNet++
Number of Vehicles used	600, 4000
Intersection used	01
Number of traffic lights used	04
Traffic light green duration	30 (s)
Simulation Map	4 leg intersection
Lanes	4 lanes on each leg
Desired distance	0.4 (m)
Tau	1 (s)
Imperfection	0.5 (s)
Critical density (d_c)	40 vehicles
Jam density (d_j)	55 vehicles

4.1.2. Implementation of Different Scenarios with Dynamically Changing Conditions

There are many situations when the platoon gets disturbed midway during the journey. There is a possibility that the leader vehicle becomes non-operational. Mostly some disturbance or obstacle intervenes the follower vehicles in platoons, and the leader vehicle does not know about the obstacle. These scenarios could help platoons of vehicles to find their way in these types of situations. Now, we discuss some of these situations in detail one by one.

When Leader Vehicle Fails

The configuration of platooning is set in such a way that all vehicles of that platoon will follow all the actions that the leader vehicle performs. If the leader vehicle fails, then the whole lane or road segment could become stuck in the worst traffic congestion. In such situations, leadership is transferred to other vehicles in the platoon, and the rest of the vehicles follow the new leader. The leadership is transferred to the vehicle nearest to the failed leader. A consensus message is sent to all follower vehicles, and, after the acknowledgement is received, another message about the new leader is sent to all vehicles, and all vehicles adjust accordingly. Now, this new vehicle is the platoon leader, and all other vehicles follow this new vehicle and move towards their destinations.

Algorithm 1: Algorithm for platooning scenarios

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1 *Start Simulation ;*
2 *Set d_c = critical density; d_j = jam density; d_n = normal density ;*
3 *Generate Vehicles (a = 1, ..., n) with aL length ;*
4 *Assign each vehicle an ID and take its O-D;*
5 *Store Vehicle ID with O-D matrix in memory ;*
6 *Get all routes and alternate routes against each O-D;*
7 *Set a global 0-D route and all local routes within the O-D;*
8 *Get the list of vehicle Ids with same global O-D and vehicles whose destination lies on local routes with global route ;*
9 *Create platoons ($P_1, P_2, ..., P_n$ of vehicles $a_1, a_2, ..., an$);*
10 *Get list of vehicles in each platoon i.e., ($a_1 P_1, a_2 P_1, a_3 P_1, a_4 P_2, a_5 P_2 ...$) ;*
11 *Assign values to Leader L_d such as speed, acceleration, min-gap etc. ;*
12 **foreach** *Platoon P at Intersection I* **do**
13 | *Get the current state of the I;*
14 | **if** *($d_c == d_j$)* **then**
15 | | *Reroute platoons on the alternate routes*
16 | **else if** *($d_c == d_n$)* **then**
17 | | *Stay on the same route*
18 **foreach** *Platoon P coming behind Intersection I* **do**
19 | *Get the current state of the the I;*
20 | **if** *Delay > threshold limit* **then**
21 | | Reroute platoons on the alternate routes
22 | **else if** *Delay < threshold limit* **then**
23 | | Stay on the same route
24 **if** *(destination arrived)* **then**
25 | Leave the platoon
26 **if** *($P_1 L_d$==inactive)* **then**
27 | *Assign new L_d to P1*
28 Get route R_1 and R_2 of P_1 and P_2;
29 **if** *(R_2 of $P_2 \in R_1$ of P_1)* **then**
30 | *Merge P_2 and P_1*
31 **if** *(Obstruction between vehicles of P_1)* **then**
32 | *Split platoon in P_1 and P_1' and assign L_d' to P_1'*
33 **if** *(All vehicles of P_1 reach Destination)* **then**
34 | *Mark P_1 as Dead*

When Multiple Platoons Come Together

When multiple platoons come together on a road segment with the same destination directions, these smaller platoons can merge to form a sizeable single platoon. In this way, inter-platoon spacing could be reduced further. Instead of instructing numerous leaders, only one leader will take instructions from the infrastructure and lead the follower vehicles outside from the congestion. All new vehicles will join the platoon's leader, going in the same direction as their destination. In this way, multiple small platoons with different origins but the same destination will merge into one platoon, and smooth traffic progression is ensured. Even though the vehicles were in separate lanes and on roads, as long as the destination is the same, they will follow the leader towards their destinations.

Obstruction within Platoons

Another situation may arise when a foreign object/obstacle appears in the middle of the platoon, and the vehicles within the platoons go far away from each other. As time increases, the distance between the vehicles in the platoon also increases, and, as a result,

the leader is no longer available to the vehicles left behind. When such a situation occurs, the platoon splits up into parts, and vehicles left behind choose a new leader that will lead the platoon. The new leader will now lead the vehicles to alternate paths to their destination as the current route is blocked due to the obstacle. The new platoon will take a detour to reach its destination.

Algorithms 1 and 2 show a general overview of the proposed approach. The vehicles are using platooning strategies for efficient congestion management and collision avoidance for traffic flow management. The vehicles at the intersection and the vehicles coming behind the intersection are rerouted to alternate paths for congestion reduction and congestion avoidance. The delayed vehicles are used here for congestion detection. The threshold limit for the delay that occurred at the intersection is set according to the number of vehicles in the traffic jam. Vehicles coming behind the intersection are notified about the traffic condition on the intersection. if the delay time is not very high, then vehicles can wait for the same route and if the delay time is high the vehicle's platoons could reroute to alternate paths. If some problem occurs during the platoon's navigation, then alternate ways are discussed. Similarly, in collision avoidance, the vehicles receive notification about collisions and the location of collisions to avoid that location so that the smooth traffic flow is maintained.

Algorithm 2: Algorithm for collision Avoidance

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1   *Start Simulation* ;
2   *Generate Vehicles (a = 1, ..., n) with aL length on random lanes* ;
3   *Set all the parameters for platooning according to the Algorithm 1*;
4   *Get the lane against each vehicle's ID i.e., $(a_1L_1, a_2L_1, a_3L_1, a_4L_2, a_5L_2 ...)$* ;
5   *Generate an obstacle on the specific lane or on specific route every 10 s* ;
6   **foreach** *Platoon on the road segment* **do**
7   **if** *collision occurs* **then**
8   **if** *only one lane is blocked* **then**
9   Mark the lane as HL (Hazard Lane)
10   **else if** *whole route is blocked* **then**
11   Mark the route as HR (Hazard Route)
12   Generate warning message to all other vehicles;
13   Notify all vehicles about collision location;
14   **if** *platoon is on HL* **then**
15   change the lane
16   **else if** *platoon is not on hazard lane* **then**
17   Mark platoon as safe
18   **if** *platoon is on HR* **then**
19   Reroute the platoon on alternate route

Algorithms 1 and 2 perform best when all vehicles are fully autonomous (100% penetration rate), and there are no non-equipped vehicles present on the road. The algorithms can produce reasonable results under low penetration rates such as 40%, 30%, and 10% with some modifications such as using dedicated lanes for AV platooning and adjusting the parameters according to the mixed autonomy scenarios, as explained in [42].

4.2. Collision Avoidance Using V2V and V2I

In the second phase of our approach, we implemented the collision avoidance mechanism for AVs with V2V and V2I communication. Algorithm 2 describes the collision avoidance strategy. Road Side Units (RSU) and detectors (induction loops) are used as V2I, and V2V is implemented using OMNeT++. We ran regular traffic in the form of platoons on the intersection network and put random obstacles on the routes. In typical scenarios, the vehicles become stuck in collisions. The road network becomes a dead jam after some time due to the congestion as vehicles continuously come towards the area. These vehicles

follow the shortest path to the destination regardless of knowing any collision blocking the road. When these vehicles encounter road collisions, they either are involved in the collision or are blocked on the road until the problem is resolved. In another scenario, we used the RSUs in every lane of every road and added vehicles on the road allowing V2V and V2I communications. When a vehicle enters the road network, RSU sends a warning message to the vehicle about the collision with the obstacle present on the route using V2I. This vehicle using V2V informs other vehicles about the collision, and this whole section of vehicles takes alternate routes to avoid the blocked passages. In this way, the chances of collisions are reduced, and an efficient traffic flow is possible. Now, we present the experiments done and their results in the following sections.

5. Simulation Setup

In this section, we describe in detail the tools and simulations used for our experiments.

5.1. Network Initialization

We used the intersection road network of F-8 sector of Islamabad as OSM (Open Street Map) converted map in SUMO, as shown in Figure 3a. In Figure 3b, simulations of vehicles with different platoons are shown. Leader vehicles are shown in different colors, such as red, green, or blue, while follower vehicles are yellow. Traffic lights are also used on the intersection, which become red and green at pre-timed fixed lengths.
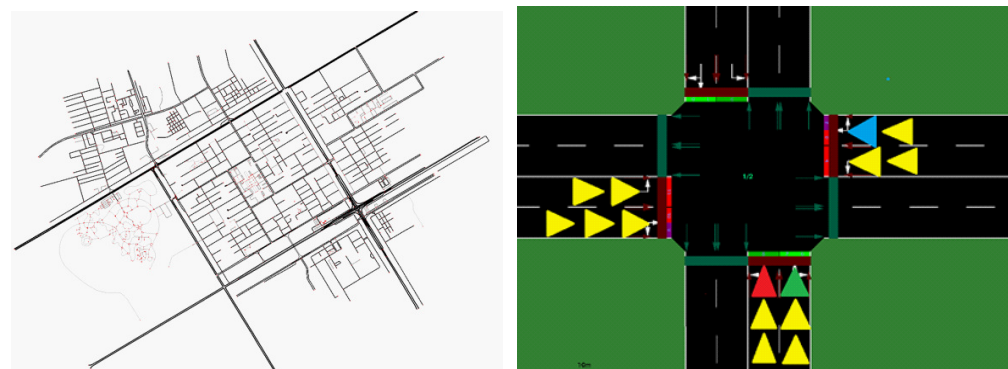
(**a**) OSM (Open Street Map) Map of F-8 Markaz Islamabad (**b**) Intersection used with multiple Platoons

Figure 3. OSM map with intersection network used for vehicles in platoons; with leader vehicles in red, green and blue.

5.2. Random Trips

The vehicles entered into the network using the Python script "randomTrips.py" in SUMO. Random numbers of vehicles enter the network at random intervals. Here are some properties of randomtrips.py.

- Randomization: Random output files are created.
- Edge Probabilities: Increases the probability that trips will start/end at the fringe of the network.
- Arrival Rate: By default, this generates vehicles with a constant period and arrival rate.
- Generating vehicles with additional parameters: It includes max speed, vehicle ID, and vehicle class (passenger, driver, etc.).
- Generating modes of traffic: Pedestrians, public transport, or vehicles.

5.3. Tools Used for Simulations

We used SUMO [43], VEINS [44], and OMNeT++ [45] for our simulations. SUMO is an open-source traffic simulator used for variety of purposes such as for optimizing traffic lights, investigating route choice, traffic forecasts, and embedding new algorithms for many

traffic scenarios. V2V communication is done by VEINS and OMNeT++. VEINS is the open source model library for OMNeT++ used as a communication technology between the vehicles. Its extensive suite of models helps traffic simulations to look more realistic and efficient. OMNeT++ is a component-based framework and library in C++ primarily used for building simulators. The domain-specific functionalities such as internet protocols, photonic networks, sensor networks, performance modeling, ad-hoc networks, and many more are provided by this framework.

5.4. V2V Using Veins and OMNeT++

Veins and OMNeT++ come with a lot of features to provide communication among vehicles. They come with fixed command and features to aid the network's vehicles to communicate with each other.OMNeT++ uses the framework of veins that provide support for the IEEE 802.11p and 1609.4 DSRC/ Wireless Access in Vehicular Environments (WAVE) network layers. It provides an interface for SUMO with TCP-based IPC using TraCI [46]. The vehicles involved in V2V communication can contact each other through OMNeT++ network simulation by sending signals warnings to the other vehicles that an accident has occurred in the corresponding lane. Thus, the vehicles that are not in the range of the corresponding RSUs can alter their route before wasting more time and fuel.

5.5. Exception Handling

The combination of strategies such as V2V with V2I plays a vital role in the vehicles' exception handling. If infrastructure fails for specific reasons, AVs could avoid obstacles using V2V and inform other cars or drive out from blocks using platooning. If, due to system failure, V2V halts, then vehicles could take benefit from the infrastructure. The combination of both techniques could significantly impact performance improvement.

6. Results and Discussions

Simulations are done using the road network maps and the intersection of F-8 Markaz Islamabad using OSM. A four-leg intersection network and road with different alternate routes for single origin-destination is used. Vehicles are rerouted to alternate routes in form of platoons with the same origin and destination or the same route used for different destinations. The results show a significant improvement in time by using V2V and V2I. Efficient traffic flow management could be achieved using a combination of strategies. Figure 4 presents the time–distance graph of the vehicles' platoons. The blue dotted line shows the desired distance between the platoon's vehicles, while the red line shows the actual distance between the vehicles. We can see from the graph that the distance starts converging towards the desired distance as the simulations run. The intra-platoon spacing between the vehicles starts reducing, which increases the lane capacity. Similarly, in Figure 5, the velocity between the vehicles in the platoon is shown. The blue dotted line in the graph shows the leader vehicle's linear velocity. The red line shows the velocity of follower vehicles. After a few seconds, we can see in the graph that follower vehicles start following the leader vehicle's velocity, although there is a slight variation in the velocity.

In Figure 6, a comparison is given: the red line shows the vehicles without platooning during the congestion, while the blue line shows the vehicles using platooning and rerouted to the alternate routes. The results show that 600 vehicles take almost 33 min of simulations to reach their destination without platooning due to the intersection's congestion. When vehicles are divided into platoons and rerouted to alternate paths, then 600 vehicles take almost 8 min to reach their destination. However, if some problems arise within the platoons, as explained in Section 4, such as if the leader fails, obstruction, etc., then this time will be increased.
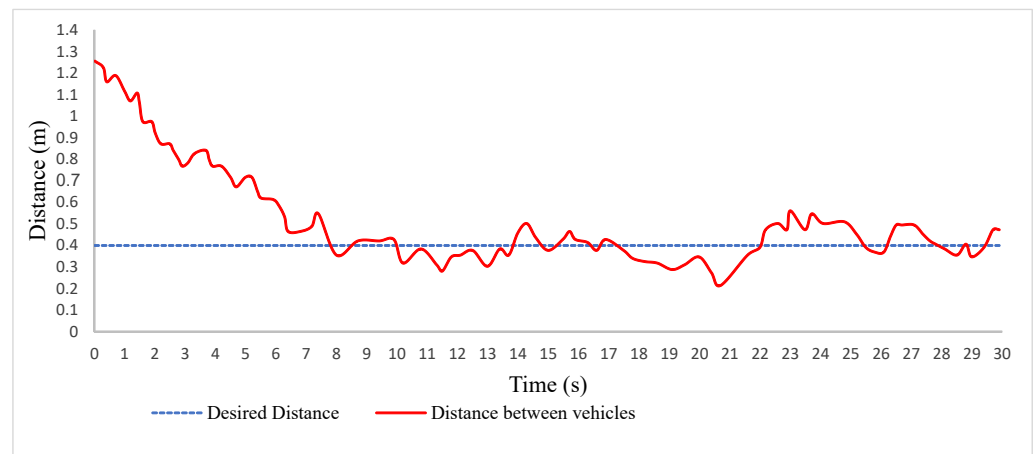
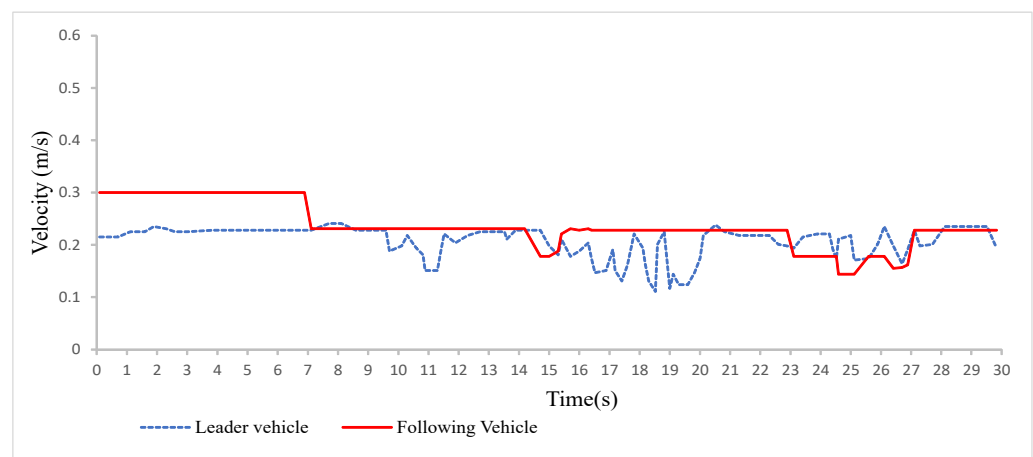**Figure 4.** Distance between vehicles vs. desired distance.

Figure 5. Velocity of leader vehicle and followers vehicle.
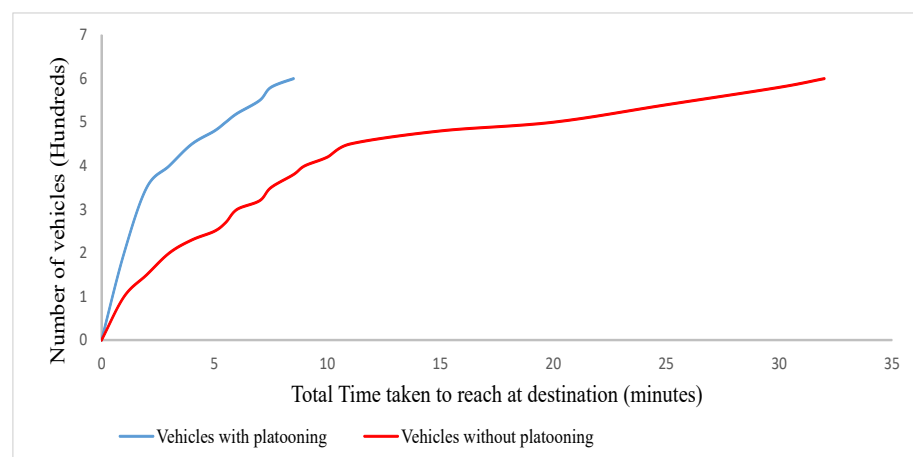

Figure 6. Comparison of vehicle's timing with and without platooning.

In Figure 7, the results of multiple scenario implementation are shown. The graph shows the computation time taken by 600 vehicles to reach their destinations. The green line in the graph shows the scenario when the leader vehicle fails; the red line shows the scenario when multiple platoons come together, that is, the merging of platoons; and the blue line shows the scenario when some obstruction comes within platoons causing the splitting of the platoons. The results show that the blue line takes more time, almost 25 min, for 600 vehicles to reach their destination. This means that, if some obstruction or

interruptions come in platoons of vehicles, then identifying it and choosing a new leader takes time. Similarly, the green line shows that if a leader vehicle fails, it takes almost 17 min to 600 vehicles to reach its destination. The time is much less than the obstruction within platoons, but there is still delay due to the selection of a new leader for the current platoon. Finally, the red line in the figure shows that merging multiple small platoons to one large platoon could significantly improve the performance of the platooning. It takes 10 min to 600 vehicles to reach their destinations. Thus, according to these results, we could suggest that merging multiple platoons into one big platoon could improve the traffic flow in the case if all the vehicles present on the road are fully autonomous.
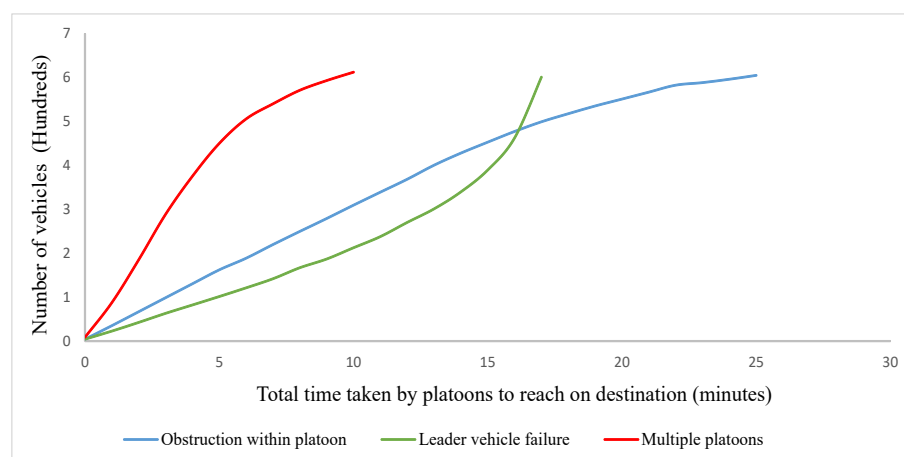

Figure 7. Comparison of different platooning scenarios.

Figure 8 illustrates the results of the collision avoidance technique using V2V and V2I. The blue line shows collision reduction results when only V2I is used, the green line shows the results when only V2V is used, and the red line displays the results when the combination of V2V and V2I is used. Every 10 s, we generate an obstacle for collision avoidance in the network for experiments. Once the collision has occurred, all other vehicles become aware of the collision's location. The lane on which the crash has happened is now called the "hazard lane" and if the whole route is blocked due to collision then the route becomes a "hazard route". Vehicles that are not in the hazard lane are considered safe. Platoons in the hazard lane actively try to change lanes away from the hazard lane. Vehicles immediately behind the crashing vehicle receive a warning. This warning notifies the vehicle's platoon that there is a crash ahead, and, therefore, it should slow down. Thus, comparing the networks, it can be seen that fewer vehicles are involved in the accident when they are in communication via V2V. The collision rate for 600 vehicles when an accident is generated every 10 s is different for each type of vehicular communication. For V2I communication, the collision rate is 73%, which is relatively very high. For V2V, the collision rate is 39%. The collision rate in the environment where V2V and V2I work together is 12.5%. Thus, V2V and V2I working together produce the least amount of collisions in the network. The results in the graphs show a significant improvement when using both V2V and V2I together.
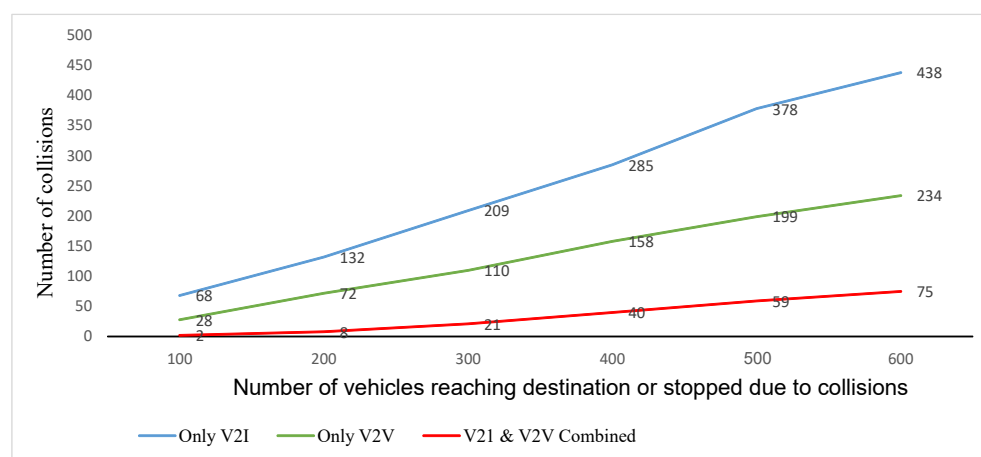
Figure 8. Graph of collisions for V2V, V2I, and V2V and V2I combined.

7. Conclusions

This paper investigates the strategies for the improvement of the traffic flow of autonomous vehicles. A two-phase approach is proposed for the improvement of traffic flow: on the first level, we use the platooning concept for congestion reduction on the intersection, whereas, on the second level, collision avoidance strategy is used. The V2V and V2I communication technology used by the vehicles is DSRC/802.11p. The results show a significant improvement in traffic flow during congestion using platoons of vehicles. Taking information from infrastructure and each other, vehicles avoid the lanes and roads where the collisions occurred. The results show a significant reduction in the collision rate, from 73% to 12.5%. Using a combination of strategies, we could improve the overall traffic flow while reducing travel times and collision rates.

For future work, we are planning to implement our strategies using new long-range cellular-vehicle to everything (C-V2X) and 5G-new radio (5G-NR) technologies and show the latency improvement comparisons.

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References

1. Mushtaq, A.; Haq, I.U.; Imtiaz, M.U.; Khan, A.; Shafiq, O. Traffic Flow Management of Autonomous Vehicles Using Deep Reinforcement Learning and Smart Rerouting. *IEEE Access* **2021**, *9*, 51005–51019. [CrossRef]
2. Van, T.N.; Geihs, K. Formal Verification of Multi-agent Plans for Vehicle Platooning. In *Context-Aware Systems and Applications, and Nature of Computation and Communication*; Springer: Berlin/Heidelberg, Germany, 2020; pp. 3–15.
3. Rios, J.; Lohn, J. A comparison of optimization approaches for nationwide traffic flow management. In Proceedings of the AIAA Guidance, Navigation, and Control Conference, Chicago, IL, USA, 10–13 August 2009; p. 6010.
4. Favilla, J.; Machion, A.; Gomide, F. Fuzzy traffic control: Adaptive strategies. In Proceedings of the 2nd IEEE International Conference on Fuzzy Systems, San Francisco, CA, USA, 28 March–1 April 1993; pp. 506–511.
5. Morando, M.M.; Tian, Q.; Truong, L.T.; Vu, H.L. Studying the safety impact of autonomous vehicles using simulation-based surrogate safety measures. *J. Adv. Transp.* **2018**, *2018*, 6135183. [CrossRef]
6. Kesting, A.; Treiber, M.; Helbing, D. Connectivity statistics of store-and-forward intervehicle communication. *IEEE Trans. Intell. Transp. Syst.* **2010**, *11*, 172–181. [CrossRef]

7. Papageorgiou, M.; Diakaki, C.; Dinopoulou, V.; Kotsialos, A.; Wang, Y. Review of road traffic control strategies. *Proc. IEEE* **2003**, *91*, 2043–2067. [CrossRef]

8. Seiler, P.; Song, B.; Hedrick, J.K. Development of a collision avoidance system. *SAE Trans.* **1998**, *107*, 1334–1340.

9. Fernandes, P.; Nunes, U. Platooning with IVC-enabled autonomous vehicles: Strategies to mitigate communication delays, improve safety and traffic flow. *IEEE Trans. Intell. Transp. Syst.* **2012**, *13*, 91–106. [CrossRef]

10. Abdel-Aty, M.A.; Kitamura, R.; Jovanis, P.P. Using stated preference data for studying the effect of advanced traffic information on drivers' route choice. *Transp. Res. Part C Emerg. Technol.* **1997**, *5*, 39–50. [CrossRef]

11. Fernandes, P.; Nunes, U. Platooning of autonomous vehicles with intervehicle communications in SUMO traffic simulator. In Proceedings of the 13th International IEEE Conference on Intelligent Transportation Systems, Funchal, Portugal, 19–22 September 2010; pp. 1313–1318.

12. Kocić, J.; Jovičić, N.; Drndarević, V. Sensors and Sensor Fusion in Autonomous Vehicles. In Proceedings of the 2018 26th Telecommunications Forum (TELFOR), Belgrade, Serbia, 20–21 November 2018; pp. 420–425. [CrossRef]

13. Zhu, L.; Yu, F.R.; Leung, V.; Wang, H.; Briso-Rodríguez, C.; Zhang, Y. Communications and Networking for Connected Vehicles. *Wirel. Commun. Mob. Comput.* **2018**, 5612785. [CrossRef]

14. Cheek, E.; Alghodhaifi, H.; Adam, C.; Andres, R.; Lakshmanan, S. Dedicated short range communications used as fail-safe in autonomous navigation. In Proceedings of the Unmanned Systems Technology XXII, Online, 27 April–8 May 2020; p. 114250P.

15. ElBatt, T.; Goel, S.K.; Holland, G.; Krishnan, H.; Parikh, J. Cooperative collision warning using dedicated short range wireless communications. In Proceedings of the 3rd International Workshop on Vehicular ad Hoc Networks, Los Angeles, CA, USA, 29 September 2006; pp. 1–9.

16. Wang, C.; Gong, S.; Zhou, A.; Li, T.; Peeta, S. Cooperative adaptive cruise control for connected autonomous vehicles by factoring communication-related constraints. *Transp. Res. Procedia* **2019**, *38*, 242–262. [CrossRef]

17. Seo, H.; Lee, K.D.; Yasukawa, S.; Peng, Y.; Sartori, P. LTE evolution for vehicle-to-everything services. *IEEE Commun. Mag.* **2016**, *54*, 22–28. [CrossRef]

18. Berger, T.; Sallez, Y.; Raileanu, S.; Tahon, C.; Trentesaux, D.; Borangiu, T. Personal rapid transit in an open-control framework. *Comput. Ind. Eng.* **2011**, *61*, 300–312. [CrossRef]

19. Alam, A.; Gattami, A.; Johansson, K.H.; Tomlin, C.J. Guaranteeing safety for heavy duty vehicle platooning: Safe set computations and experimental evaluations. *Control Eng. Pract.* **2014**, *24*, 33–41. [CrossRef]

20. Magdici, S.; Althoff, M. Adaptive cruise control with safety guarantees for autonomous vehicles. *IFAC-PapersOnLine* **2017**, *50*, 5774–5781. [CrossRef]

21. Gong, S.; Zhou, A.; Peeta, S. Cooperative adaptive cruise control for a platoon of connected and autonomous vehicles considering dynamic information flow topology. *Transp. Res. Rec.* **2019**, *2673*, 185–198. [CrossRef]

22. Bang, S.; Ahn, S. Platooning strategy for connected and autonomous vehicles: transition from light traffic. *Transp. Res. Rec.* **2017**, *2623*, 73–81. [CrossRef]

23. Abualhoul, M.Y.; Shagdar, O.; Nashashibi, F. Visible light inter-vehicle communication for platooning of autonomous vehicles. In Proceedings of the 2016 IEEE Intelligent Vehicles Symposium (IV), Gothenburg, Sweden, 19–22 June 2016; pp. 508–513.

24. Wang, J.; Gong, S.; Peeta, S.; Lu, L. A real-time deployable model predictive control-based cooperative platooning approach for connected and autonomous vehicles. *Transp. Res. Part B Methodol.* **2019**, *128*, 271–301. [CrossRef]

25. Rezgui, J.; Gagné, É.; Blain, G.; St-Pierre, O.; Harvey, M. Platooning of Autonomous Vehicles with Artificial Intelligence V2I Communications and Navigation Algorithm. In Proceedings of the 2020 Global Information Infrastructure and Networking Symposium (GIIS), Tunis, Tunisia, 28–30 October 2020; pp. 1–6.

26. Firoozi, R.; Zhang, X.; Borrelli, F. Formation and reconfiguration of tight multi-lane platoons. *Control Eng. Pract.* **2021**, *108*, 104714. [CrossRef]

27. Horowitz, R.; Tan, C.W.; Sun, X. *An Efficient Lane Change Maneuver for Platoons of Vehicles in an Automated Highway System*; eScholarship: Los Angeles, CA, USA, 2004.

28. Wang, Z.; Wu, G.; Hao, P.; Boriboonsomsin, K.; Barth, M. Developing a platoon-wide eco-cooperative adaptive cruise control (CACC) system. In Proceedings of the 2017 IEEE Intelligent Vehicles Symposium (IV), Los Angeles, CA, USA, 11–14 June 2017; pp. 1256–1261.

29. Canudas de Wit, C.; Brogliato, B. Stability issues for vehicle platooning in automated highway systems. In Proceedings of the 1999 IEEE International Conference on Control Applications (Cat. No.99CH36328), Kohala Coast, HI, USA, 22–27 August 1999; Volume 2, pp. 1377–1382. [CrossRef]

30. Tatchikou, R.; Biswas, S.; Dion, F. Cooperative vehicle collision avoidance using inter-vehicle packet forwarding. In Proceedings of the GLOBECOM'05, IEEE Global Telecommunications Conference, St. Louis, MO, USA, 28 November–2 December 2005; Volume 5, p. 5.

31. Garcia-Roger, D.; González, E.E.; Martín-Sacristán, D.; Monserrat, J.F. V2X support in 3GPP specifications: From 4G to 5G and beyond. *IEEE Access* **2020**, *8*, 190946–190963. [CrossRef]

32. Etsi, G. *Service Requirements for Enhanced V2X Scenarios*; 3GPP TS 22.186; ETSI: Sophia Antipolis, France, 2019.

33. Vukadinovic, V.; Bakowski, K.; Marsch, P.; Garcia, I.D.; Xu, H.; Sybis, M.; Sroka, P.; Wesolowski, K.; Lister, D.; Thibault, I. 3GPP C-V2X and IEEE 802.11 p for Vehicle-to-Vehicle communications in highway platooning scenarios. *Ad Hoc Netw.* **2018**, *74*, 17–29. [CrossRef]

34. Nardini, G.; Virdis, A.; Campolo, C.; Molinaro, A.; Stea, G. Cellular-V2X communications for platooning: Design and evaluation. *Sensors* **2018**, *18*, 1527. [CrossRef]

35. Choi, Y.; Jimenez, H.; Mavris, D.N. Two-layer obstacle collision avoidance with machine learning for more energy-efficient unmanned aircraft trajectories. *Robot. Auton. Syst.* **2017**, *98*, 158–173. [CrossRef]

36. Tung, L.C.; Mena, J.; Gerla, M.; Sommer, C. A cluster based architecture for intersection collision avoidance using heterogeneous networks. In Proceedings of the 2013 12th Annual Mediterranean Ad Hoc Networking Workshop (MED-HOC-NET), Ajaccio, France, 24–26 June 2013; pp. 82–88.

37. Yang, J.; Coughlin, J.F. In-vehicle technology for self-driving cars: Advantages and challenges for aging drivers. *Int. J. Automot. Technol.* **2014**, *15*, 333–340. [CrossRef]

38. Wikipedia. Traffic Flow. 2021. Available online: https://en.wikipedia.org/wiki/Traffic_flow (accessed on 5 March 2021).

39. Treiber, M.; Kesting, A. Traffic flow dynamics. In *Traffic Flow Dynamics: Data, Models and Simulation*; Springer: Berlin/Heidelberg, Germany, 2013.

40. Edie, L.C. *Discussion of Traffic Stream Measurements and Definitions*; Port of New York Authority: New York, NY, USA, 1963.

41. Michaud, F.; Lepage, P.; Frenette, P.; Letourneau, D.; Gaubert, N. Coordinated maneuvering of automated vehicles in platoons. *IEEE Trans. Intell. Transp. Syst.* **2006**, *7*, 437–447. [CrossRef]

42. Kesting, A.; Treiber, M.; Schönhof, M.; Helbing, D. Adaptive cruise control design for active congestion avoidance. *Transp. Res. Part C Emerg. Technol.* **2008**, *16*, 668–683. [CrossRef]

43. Lopez, P.A.; Behrisch, M.; Bieker-Walz, L.; Erdmann, J.; Flötteröd, Y.P.; Hilbrich, R.; Lücken, L.; Rummel, J.; Wagner, P.; Wießner, E. Microscopic Traffic Simulation using SUMO. In Proceedings of the The 21st IEEE International Conference on Intelligent Transportation Systems, Maui, HI, USA, 4–7 November 2018.

44. Sommer, C.; Eckhoff, D.; Brummer, A.; Buse, D.S.; Hagenauer, F.; Joerer, S.; Segata, M. Veins: The open source vehicular network simulation framework. In *Recent Advances in Network Simulation*; Springer: Berlin/Heidelberg, Germany, 2019; pp. 215–252.

45. Varga, A.; Hornig, R. An overview of the OMNeT++ simulation environment. In Proceedings of the 1st International Conference on Simulation Tools and Techniques for Communications, Networks and Systems & Workshops, Marseille, France, 3–7 March 2008; pp. 1–10.

46. Sliwa, B.; Pillmann, J.; Eckermann, F.; Habel, L.; Schreckenberg, M.; Wietfeld, C. Lightweight joint simulation of vehicular mobility and communication with LIMoSim. In Proceedings of the 2017 IEEE Vehicular Networking Conference (VNC), Turin, Italy, 27–29 November 2017; pp. 81–88.