Platoon-based Traffic Management Method for Autonomous Driving Systems

Hamed Fazli
School of electrical engineering
Iran University of Science and Technology
Tehran/Iran
Hamed_fazli@elec.iust.ir

Hadi Shahriar Shahhoseini
School of electrical engineering
Iran University of Science and Technology
Tehran/Iran
shahhoseini@iust.ac.ir

Abstract—**In recent decades, by the advance in the technology and the advent of autonomous driving systems, platooning play a pivotal role in smart cities. The amount of communication data between platoons via Vehicular Ad-hoc Network (VANET) are large enough to make it a complex problem for speed and inter-distance control modelling. In this paper, a simplified model based on analytical equations has been proposed to improve the comfort driving and passenger's safety and congestion management in on-ramps of highways. Maximum deceleration force and current velocity of vehicles are the key factors of this model. Moreover, we considered the instantaneous speed for the individual vehicles when entering the highway from on-ramps. Using this model, it is possible to place on-ramp vehicles between the gaps of platoons. Achievements of this paper showed that the flow of vehicles in on-ramps has been improved more efficiently in comparison with previous method.**

Keywords-component; Vehicular traffic management; Smart city; VANET; Autonomous vehicles

I. Introduction

Generally, using the same resources due to limited infrastructure in the environment around us by two or more client leads to congestion. For example, every day we observe many people who are waiting in long queues at banks or airports .The fundamental reason for this situations is the simultaneity which is the consequence of the clients who requests at the same time for the same service. As a result there should be mechanisms for managing them. The main solution for overcoming this problem is avoiding the concurrency.

The domain of transportation exclusively urban transportation is one of the most displeased areas of the congestion, as the number of cars in roads exceed the capacity of the roads. This high population of cars at on and off ramps or intersections creates the concurrency and then traffic congestion. This trend is result of everyday increase in the number of cars produced by companies and the low probability for constructing new infrastructure or renewing the old infrastructures to answer new demands which creates the issue of density. Consequently, detrimental outcomes of the high density inside the cities such as increase in fuel consumption which makes many financial problems for governments and the car owners and many pollution for nature. Another challenge of congestion is wasting the useful time behind of it which in 2015 at urban area causes about 6.9 billion hour time wasted and 3.1 billion gallons more fuel consumption [1].

The main challenge related to vehicular system is the issue of safety, as World Health Organization (WHO) announced 1.2 million death per year happen in accidents [2]. The World Bank statistics reveal that $500 billion loss on international economy caused by accidents [3]. In this regard, the main challenge and main reason for the accidents as mentioned in [4] about 92%, is directly related to human realization error (the negligent of drivers, driver's distraction) and human decision errors (fast driving, incorrect calculation of the distance between cars). In domain of transportation trough the time cities have experienced many transportation systems. Recently due to advance in communication technologies, processing power, and technologies related to sensing in traffic management, safe driving, and GPS navigation [5] a large progress have been experienced. Target tracking wireless sensor networks [6] can be deployed insides the vehicles and around the highway to have a fully connected system.

The new technologies help to develop more effective and modern vehicular systems. There are many issues that affect on the system efficiency such as storing the huge amount of data, needs to high speed processing power and error-free transmission module, etc. Massively parallel processing system can be a solution [7], while reconfigurable processing can help in making adaptive processing systems [8].

Platooning refers to more than two vehicle which are traveling in a highway consecutively by leading of a leader (PI) with a safe distance between them.Generally, spacing strategy has been used for determining the minimum distance between vehicles inside a platoon which using this technique leads to the decreasing in distance. In this term, spacing strategies are mainly categorized in two classes, i: constant policy and ii: velocity dependent policy. In constant strategy, the inter-distance between vehicles dose not relay on the speed of vehicles. In [9] it have been shown that this strategy can increase the throughput of the highway in compare by velocity dependent strategy. In contrast, velocity dependent policy vehicles calculate the inter-distance with considering the speed which reducing the time leads to an increase in throughput. The target velocity controlled by PI and road side unit. The researches on vehicle platooning clarified that throughput of traffic flow directly increase by using of platooning [10]. Also, safety as an important component of ITS have been investigated [11].The Intelligent Transportation System (ITS) as a crucial component is ruling to answer the problem of traffic congestion, safety, and related issues. The routing is similar to the computer network where many algorithms have been developed [12]. The security issues and using secure protocols for data exchange would be vital such as many other network-based applications [13]. Many facets of ITS have been investigated by researchers such as autonomous driving system, and platooning which made many advance in safe driving, traffic management, and reducing the fuel consumption.

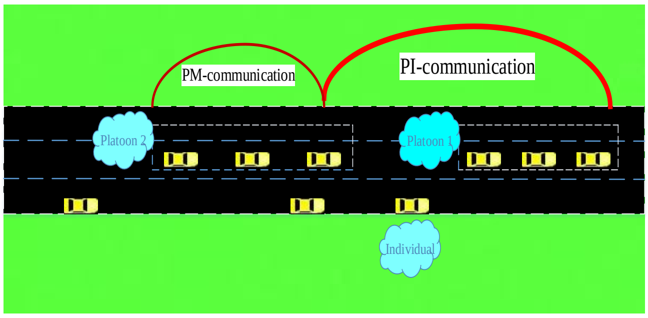

Figure1. Platoon formation in groups and vehicular communication Between PIS and PMS

II. RELATED WORK

One important issue which should be more considered is that because of human decision about the safe distance current road infrastructure are not being used in the maximum capacity. Also, because of the human reaction time (0.25s) which is more than what should be to ensure the collision avoidance in highways, autonomous vehicles as a fundamental solution has played roll. As mentioned in previous section platooning leads to diminishing in inter_ distance between and increasing in the number of vehicles inside the platoons. By using the autonomous vehicle system it should be safer and more effective to use platooning.

In [14] the authors mentioned a traffic management and networking in order to be used in autonomous driving systems. Their model consist of multi-lane multi-segment highway. In this model vehicles inside the roads are in platoons, beside the PI acts as a member of its platoon which coordinate with roadside unit and the vehicles in platoon and other PIs. Also the authors introduce a new scheme for V2V communication for vehicles which are passing in a neighborhood.

In [15] a protocol for self- driving vehicles have been presented which considers two different line with divers priority meet and their protocol used to ensure the safety. Focus on merging point for cooperation between vehicles which are using V2V communication and sensor based precipitation.

In [16] lane assignment for cars in highways in order to heighten the performance considering successful exit on their way to destination. In [17] a new hybrid system which encompasses discreet cooperative maneuver switch and continuous vehicle motion control have been proposed for a multi-vehicle cooperative control system with a distributed control structure. The method allows the automated vehicles individually conduct routing and movement control. Using the Artificial Potential Field (APF) approach is the main solution of the work.

III. HIGHWAY SYSTEM MODEL

In this paper we considered a highway system with on and off ramps. The system consist of cells with an access ramps and an exit ramps which illustrated in figure 2. The main way can consist of more than two lanes but for on and off ramp we assume only on lane.

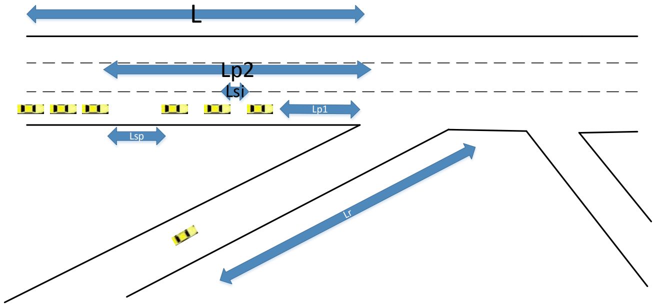

Figure 2. The highway system model considered In this paper including parameters for our model

For the highway system illustrated in figure 2 we consider that in control zone which in figure shown by the length of L only the cares at right most lane can leave the highway from of ramps. The vehicles which are in platoons in other lanes should join to a platoon in right most lane to be able to leave the highway.

Table1. The notations used in this paper

Parameter	Definition
L	minimum distance for control zone
Lpi	distance of PIi with merging point
Lsi	safe inter-vehicle distance inside the platoons
Lsp	safe distance between two successive platoons
Lp	length of platoon
Lr	distance of ramp vehicle with merging point
Vp	speed of platoon leaders which platoon members by a safe distance have the same velocity
Vr	speed of on ramp vehicle
u	nominal deceleration of a vehicle
s	nominal deceleration of a vehicle
Vtg	target velocity of vehicles
Δu	deviation of declaration of its nominal value
n	number of vehicles inside the platoon
g	extra minimum gap distance between platoons
Vrm	the maximum velocity in on ramp

IV. PLATOONING TRAFFIC MANAGEMENT METHOD

The distance between vehicles inside the platoon and the distance between two successive platoon (the last vehicle in platoon i and the PI of the platoon i+1), and the length of a platoon which filled with n vehicle is defined as:

$$Lsi = s + \alpha \frac{v^2}{2u} \quad (1)$$

$$Lsp = Lsi + g = s + \alpha \frac{v^2}{2u} + \beta \left(s + \alpha \frac{v^2}{2u} \right) =$$

$$(1+\beta)\left(s + \alpha \frac{v^2}{2u} \right) \quad (2)$$

$$Lp = (n-1) * Lsi \quad (3)$$

Where s=6m, α=0.2, u=3m/s^2, β= 1.

As the [13] explained about the equation, for a safe distance between vehicles in order to avoid collision, α (α ≤1) have been introduced to represent the dispersion of declaration. The factor α needed because of the fact that while a vehicle is decelerating, it still move forward. So, it have been added to the subsequent for avoiding collision. As, mentioned above the extra gap distance g based on the flow of vehicles which should be allowed to enter the highway from on ramp is needed to provide the safety merging. The change in parameter β increases or decreases the number of cars which allowed to move in the main link of highway.

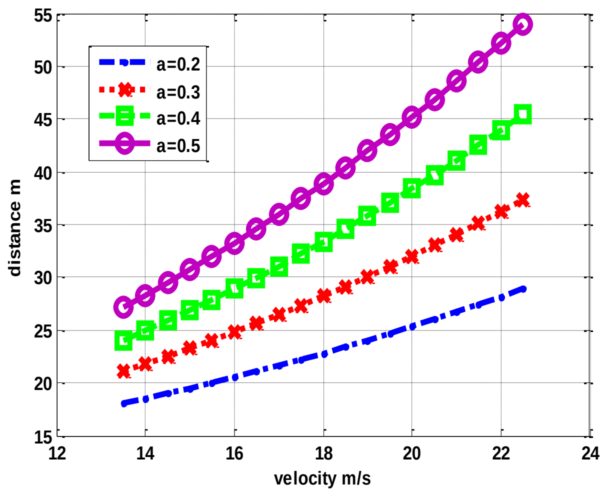

Figure 3. The safe distance between vehicles inside the platoon based on the velocity

As a basic principal of platooning, the vehicles in on ramp only when a platoon passes the merging point can enter the highway. So, vehicles in on ramp experience two different time while they enter the on ramp. First, the time that they should spend until merging point, and second the time that they should wait until they permitted into the highway.

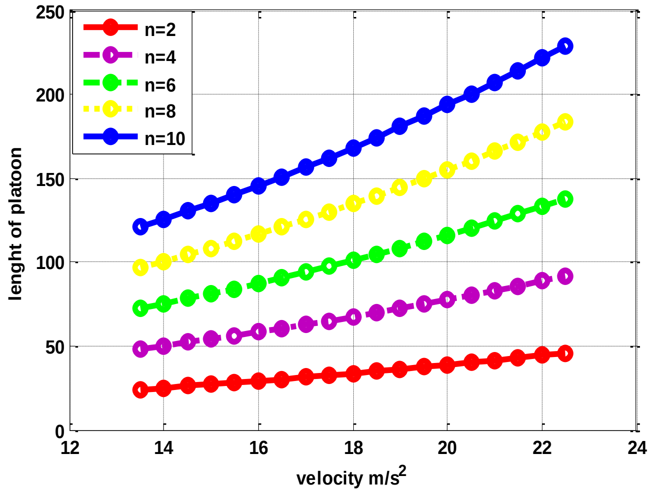

Figure 4. The safe distance between Platoon leaders based on the speed of the PIs

$$T = T_d + \frac{l}{v_r} \quad (4)$$

In this equation T_d represent the delay time that vehicles should wait for allowing to enter the highway and $\frac{l}{V_r}$ is the time in which vehicles spend till merging point. Let suppose that the vehicle in on ramp move through its way as it achieve the highway exactly after a platoon crosses the merging point. In this regard, the time that the vehicle should wait for permission will be omitted. The omission of the waiting time leads to avoiding the traffic congestion in on ramps, while, the throughput of the main link won't change. To determine the target velocity in which on ramp vehicle could minimize the waiting time, at first we should calculate the time that on ramp vehicle access the merging point which is

$$Tr = \frac{Lr}{Vr} \quad (5)$$

In here we considered that the vehicles after detecting have a constant velocity. Tr is the time that vehicle move along the on ramp, Lr is the minimum distance that we consider for cooperation (which is the distance for control zone, a zone that any calculation is based on the length of this zone, for on ramp it depends on the ramp length that we cannot change it, but for main link it depends on the previous cell off ramp which can be too long or too short), and Vr is the velocity that vehicle has after entering the control zone. As platoons are moving with platoon leaders' speed in the highway, the elapsed time for a platoon from entering the control zone till passing the merging point is $\frac{L}{VP}$ Represent the elapsed time for PI, and $\frac{(n-1)Lsi}{Vp}$ the elapsed

$$Tpk = \frac{L + (n-1)Lsi}{Vp}$$

$$= \frac{L + (n-1)(s + \alpha \frac{v^2}{2u})}{Vp} \quad (6)$$

time for PMs. After detecting a vehicle in on ramp and calculating the time for it, we calculate the time for all platoons which are in the control zone. Then we should select two consecutive platoons that the time for on ramp vehicle fixed between the platoons time which means.

$$Tpi + 1 < Tr < Tpi \quad (7)$$

Tpi = $\frac{Lpi+(n-1)Lsi}{Vp}$ is the elapsed time for platoon i, and Tpi+1=$\frac{Lpi+1}{Vp}$. It is possible that the Tr equals to time for a platoon. In this situation because of the priority that the main link has we cannot reduce the speed for the platoon so we consider the time between that platoon and the next platoon. There is two situation here. First, without any change in the speed of on ramp vehicle its time fixes between the two platoons which means the arrival time for the vehicle be Tpi plus elapsed time for safe distance that we will discuss then. In this situation we allow the vehicle to continue its way and join the highway link with no stop or abatement in its speed. Second, the time of accessing the ramp dose not satisfy the situation for equation 4. In this situation the vehicle should increase or decrease the speed to be in a safe distance from platoons. So, for this we have to calculate the target velocity. We calculated the speed by using the arrival time of front platoon plus safe distance

$$Trn = Tpi + Ts = \frac{Lpi+(n-1)(s+\alpha\frac{Vp^2}{2u})}{Vp} + \frac{s+\alpha\frac{Vr^2}{2u}}{Vr} \quad (8)$$

$$Vtag = \frac{Trn}{Lr} \quad (9)$$

Trn Is new time for ramp vehicle to adapt its speed for achieving the entry exactly after a safe distance of the platoon. As it is clear, if the new time is greater than the old time the vehicle should decrease its speed and if the new time is smaller than old the vehicle should increase its speed. By using the strategy the delay time which vehicles should stay to be admitted enter the highway will be omitted. An assumption that we considered here is that the acceleration or deceleration time for on ramp vehicle to change its speed can be avoided.

The analyses provided in previous section has an upper bound which limits the entering without any time elapsing for permission. The first factors which effects on the emerging is the rate of vehicles in the main link of highway which in our model is the rate of platoons in the highway link because we assumed that only between two platoons a vehicle can emerge into the highway link. The second factor impressing is the rate of vehicles in the on ramp.

To guaranty that the next vehicle which is coming from on ramp continuous its way with no delay it should reaches the merging point after the next platoon. As the platoons have a fix velocity relative to front and previous platoon, the target velocity for on ramp vehicles which have been investigated in equation 9 at maximum can be equal to velocity of the front vehicle by the condition that the minimum distance form the next vehicle does not be less than the equation 3 distance. As a result if the distance between the front car and the former car exceeds the minimum distance by fixing the target velocity we can achieve the maximum ratio of vehicles in on ramp without any stop.

$$Trnx = \frac{g + (n-1) * Lsi}{Vp} + Tr \quad (10)$$

$$\rho max = \frac{1}{\Delta T} = \frac{Vp}{\beta\left(s + \alpha\frac{Vp^2}{2u}\right) + (n-1) * (s + \alpha\frac{Vp^2}{2u})} \quad (11)$$

The equation 10 clarifies that the minimum distance between two consecutive vehicles in on ramp depends on the platoon' velocity and the length of platoon. Equation 11 clarifies the maximum rate of vehicles at the on ramp. Obviously the ratio is associated with the number of vehicles inside the platoons and the speed of platoons. Another factor for preventing the length of on ramp.

In figure 5 we can see that the impression of the platoon velocity cannot change the ratio of vehicles in on ramps. The reason for this is that as it is by increasing the speed of platoon it can move faster to pass the on ramp but the inter distance between the vehicles in platoon will increase to so the total time won't change much.

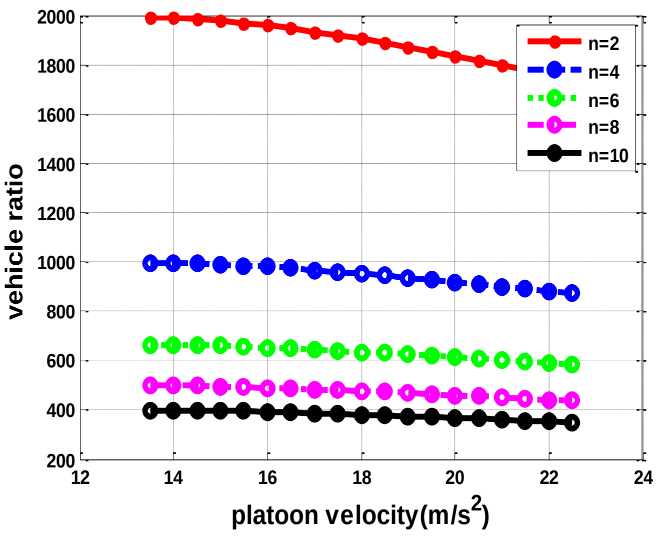

Figure 5.Ratio of vehicles in on ramp based on the velocity of the platoons

Figure 6 illustrates that by considering the velocity of the platoon in a constant rate any increase in the number of vehicles in platoons, results to decrease in the ratio of vehicles at on ramps. While this happens the ratio of vehicles in main road will increase. Consequently, in order to increase the efficiency of the junction at on and off ramps we have to consider the flow of vehicles in each line. Based on this flow we should elect the number of vehicles in platoons.

For example, if the flow of traffic in the main line of highway is more than the flow of the traffic in the on ramp, we can add the number of vehicles in each platoon to be able to control the traffic flow. In contrast, if the flow of vehicles is more in the on ramp, by reducing the number of vehicles in platoon we can increase the flow in on ramp. As a result, the most important factor is to reduce the concurrency at margin point.

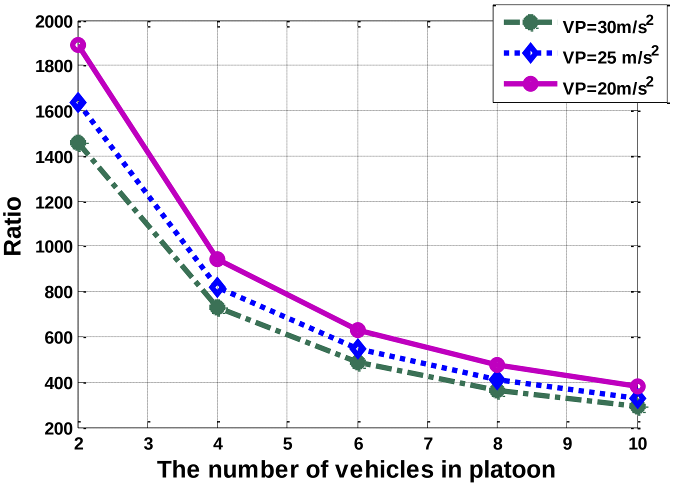

Figure 6. Ratio of vehicles in on ramp considering Fixed velocity of PIs

V. CONCLUSION

In this paper, we presented a method to manage the traffic conditions on the highway's on-ramps. It was shown that on-ramps were the bottleneck for vehicular traffic management. To prevent congestion at the head points, we proposed a speed model based on the on-ramps distance, entering velocity and maximum deceleration force. Using this model, it was possible to place individual vehicles between gaps of platoons in main highway link. Several considerations such as vehicles flow in on-ramp, number of platoon vehicles, and their speed were added to this model to compute upper bound for a non-stop condition of vehicles. We observed that the cooperation between main link of highway and on ramp is the most important factor for controlling the traffic flow and also increasing the efficiency of the highway merging point.

In future work, more lanes in on-ramps will be investigated in this model and also, on-ramps vehicle platooning is another topic that will be taken into account.

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