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# IMPLEMENTING RSU WITH TRUST AUTHORITY IN VANET-ENABLED DA-PLATOON

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***Abstract*-With the advance of technologies, the performance of platoons can be further enhanced by vehicular ad hoc networks (VANETs). Many studies have been conducted on the dynamics of a VANET-enabled platoon under traffic disturbance, which is a common scenario on a highway. However, most of them do not consider the impact of platoon dynamics on the behaviors of VANETs. In this paper, we will investigate the dynamics of the VANET-enabled platoon from an integrated perspective. In particular, we first propose a novel disturbance-adaptive platoon (DA-Platoon) architecture, in which a platoon controller shall adapt to the disturbance scenario and shall consider both VANET and platoon dynamics requirements. Grouping vehicles into platoons can improve road capacity and energy efficiency. Moreover, most existing studies focus on how to maintain the stability of a platoon and do not address how to mitigate negative effects of traffic disturbance, such as, increased fuel consumption, and increased exhaust emission. we conduct extensive simulation experiments, which not only validate our analysis but also demonstrate the effectiveness of the proposed driving strategy to build up an RSU as a proposed system and also to achieve parallel movement of platoon. However malicious attackers can also pass fake messages, which can be overcome using our concept of trust authority.**

***Keywords-Disturbance-adaptive platoon (DA-Platoon), driving strategy, RSU(Road side Unit) platoon dynamics, platoon parameters, traffic disturbance, vehicle platoon, vehicular ad hoc networks (VANETs).***

## I. INTRODUCTION

When traveling on a highway, a group of consecutive Vehicles can form a platoon, in which a nonleading vehicle maintains a small distance with the preceding vehicle1.In the literature, it has been shown that there are many benefits to driving vehicles in platoon patterns. First, since adjacent vehicles are close to each other road capacity can be increased, and traffic congestion may be decreased accordingly. Second, the platoon pattern can reduce energy consumption and exhaust emissions considerably because the streamlining of vehicles in a platoon can minimize air drag. Third, with the help of advanced technologies, driving in a

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platoon can be safer and more comfortable. To facilitate platoons, two important technologies have been introduced in the past decade, specifically, autonomous cruise control (ACC) [3] and vehicular ad hoc networks (VANETs) [4]–[6]. The ACC system with laser or radar sensors can obtain the distance to the preceding vehicle and regulate the movements of individual vehicles in a platoon. On the other hand, VANETs not only help form and maintain a platoon but also enable a vehicle to exchange traffic information with neighboring vehicles or infrastructures, which may improve traffic safety, efficiency, and comfortability. In the past few years, a lot of studies have been conducted on such VANET-enabled platoons [7], which can be classified into two categories. In the first one, studies mainly address VANET issues, such as VANET connectivity, data dissemination protocol and routing techniques, MAC scheduling, etc. [8]–[10], based on an existing platoon. In the second category, most studies are about traffic dynamics control and performance optimization by managing and controlling platoons [1], [11]– [19], with the help of an existing VANET. In this paper, we assume that a VANET has already been set up, and we will investigate the dynamics of a VANET-enabled platoon system. Specifically, we investigate the dynamics of a VANET enabled platoon under traffic disturbance, which is a common scenario on a highway. In practice, such a system may be unstable under certain disturbance scenarios. Therefore, in the literature, most existing studies on the VANET-enabled platoon system are focused on maintaining the stability of a platoon. Typically, they address the design and evaluation of the platoon controller, which specifies the driving strategy based on the observed traffic dynamics with different design objectives. For instance, for intraplatoon dynamics, Seiler et al. in [19] assumed that each vehicle only has the relative position to its preceding vehicle and that a predecessor-following control strategy is applied. For such a system, the authors studied disturbance propagation in a platoon and showed error amplification of intraplatoon spacing. To maintain constant intraplatoon spacing, a predecessor-leader control strategy was proposed in [16] and [18], wherein each vehicle should get information from both its preceding vehicle and the platoon leader. In [15], the constant-time headway policy was applied while each vehicle can get the kinematics status (location, velocity, acceleration, etc.) of the preceding vehicle via the VANET. Although existing studies are important to the applicability of a platoon, there are still many open issues. First, it is unclear how platoon dynamics can affect the behaviors of the VANET during disturbance. For example, the acceleration of a preceding vehicle can enlarge the gap between vehicles or the distance between adjacent platoons, which may lead to not only platoon splitting but also unreliable V2V communication with high packet loss and large delay. On the other hand, the deceleration of the preceding vehicle may lead to the merger between adjacent platoons with close distance. The second issue is that most existing studies focus on how to maintain the stability of a platoon (e.g., constant intraplatoon spacing) and do not address how to mitigate the negative effects of traffic disturbances, such as uncomfortable passenger experience,increased fuel consumption, and increased exhaust emission. In practice, traffic disturbances could cause frequently and sharply accelerating and decelerating, which results in not only uncomfortable driving patterns but also significant fuel consumption and exhaust emissions [17]. In this case, it will be desirable to utilize the capability of VANETs to mitigate such negative effects. To address these issues, in this paper, we investigate the dynamics of a VANET-enabled platoon from an integrated perspective. In particular, we first propose a novel disturbance adaptive platoon (DA-Platoon) architecture, with which a DA-Platoon dynamic system can be defined.

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Our main contributions in this paper are listed as follows.
1) We propose a novel DA-Platoon architecture in which we consider both traffic dynamics under disturbances and the constraints due to VANET communications.
2) We investigate the characteristic of DA-Platoon dynamics under disturbance. Based on the analytical model, we derive the desired RSU to communicate with the leader and the tail vehicle.
3) To mitigate the negative effects of traffic disturbances, we propose a novel driving strategy for the leading vehicle of a platoon, with which we can obtain the desired interplatoon spacing that can help achieve the desired traffic dynamics and that does not violate the VANET constraints in disturbance scenarios.
4) We achieve parallel order of platoon formation between the same LAN and thereby divide them accordingly.
5) Inorder to avoid malicious attacks, we provide a trust authority to indicate the fake messages and stop the unnecessary attacks.

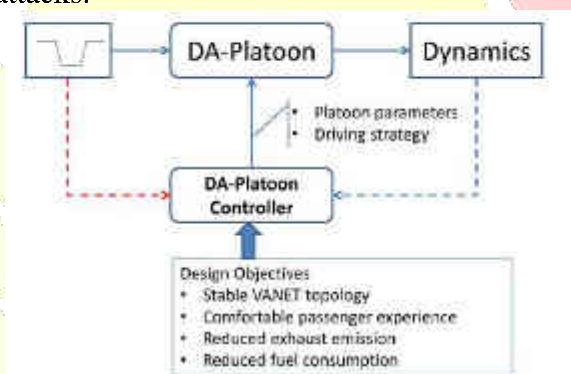


*fig.1* DA Enabled Platoon Architecture

## II. RELATED WORKS

### A. Platoon Management System

In the literature, some studies assume that an existing platoon is naturally formed [13], whereas others consider platoon formation, merging, and splitting with the help of a VANET [16].The existing studies can be distinguished according to the platoon management protocol and the platoon management strategy. The platoon management protocol enables vehicles to communicate with one another. The platoon management strategy determines the members of a platoon and the roles of individual vehicles based on various design objectives. In terms of the platoon management protocol, a filter multicast protocol was proposed in [12] to realize dynamic platoon-identification (ID) allocation, platoon dynamic formation, and management. A finite-state machine model was developed in [14] to describe the operating process of the platooning protocol. In a more general sense, many existing protocols for clustering in mobile ad hoc networks can be applied to support platoon management. For example, Taleb et al. presented a dynamic clustering mechanism to form clusters with a cooperative collision-avoidance scheme [6]. In terms of the platoon management strategy, Uchikawa et al. in [12] categorized vehicles into three roles, namely, master, member, and normal vehicle, according to their relative positions and communication range and then formed a platoon based on the roles of nearby vehicles. In [14], the main objective is to quickly identify the platoon, where a prediction scheme

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was designed to accelerate platoon formation when some vehicles are moving toward a different direction (i.e., platoon splitting). In [1], the objectives include 1) to maximize the platoon size and 2) to maximize the lifetime of a platoon. To reach these goals, Hall and Chin designed a scheme to group vehicles based on their destination at the entrance ramp. Compared with existing studies on the platoon management system, our study can be considered a platoon management strategy, in which our objective is to satisfy both VANET connectivity requirements and traffic dynamics requirements. Therefore, existing platoon management protocols can be used to form a platoon with the desired platoon parameters.

*B. Intraplatoon Dynamics*

In a single platoon, many previous studies focused on intraplatoon dynamics, which describe the transient and steady responses of a platoon, including intraplatoon spacing, velocity and acceleration trajectory of each vehicle, etc., under certain spacing policy and control strategy. In [19], Seiler et al. analyzed disturbance propagation in a platoon and showed error amplification of intraplatoon spacing under a predecessor-following control strategy, in which each vehicle only has the relative position to its preceding vehicle. To maintain constant intraplatoon spacing, a predecessor-leader control strategy [18] is proposed wherein each vehicle should

get information from both its preceding vehicle and the platoon leader. To realize this strategy, the cooperative ACC (CACC) has been proposed to maintain the stability of a given platoon [15], [16]. Theoretical and experimental results showed that V2V communications enable driving at small intervehicle distances while string stability is guaranteed. A general design of the CACC system has been proposed in [1], adopting a constant-time

headway policy in a decentralized control framework. In [16], it has been shown that the constant-spacing policy with V2V communications can increase the traffic throughput. A new platoon control method, which is called consensus control, is proposed in [2], where vehicles are deployed to converge the weighted intraplatoon spacing to a constant and maintain a constant platoon length at the same time. Normally, a vehicle has two operational modes, namely, spacing control mode and speed control mode. To get an optimized traffic flow performance, it is critical for the vehicle to design a suitable switching logic that decides when to switch between the two operational modes. In [14], a switching strategy is proposed for ACC-equipped vehicles in a platoon, which designs a constant-deceleration spacing control model by way of Range (R) versus Range-rate diagram. Despite the potentials, it is very challenging to apply VANETs for intraplatoon control because it is still difficult to guarantee reliable communications in realistic scenarios, where transmission delay and errors can occur due to the mobility of vehicles, the transmission contention, and the topology change in VANETs. Therefore, in this paper, we only apply ACC for intraplatoon control. In particular, we apply the IDM, which is essentially based on the constant-time headway control.

*C. DA-Platoon Architecture*

Although there are many existing studies on the platoon dynamic system under disturbance, we note that there are still many open issues, including the impact of platoon dynamics on VANET behaviors and how to mitigate negative effects due to traffic disturbance. To address these important issues, we propose a new DA-Platoon architecture, where we jointly consider VANET requirements and traffic dynamics requirements under disturbances. In the general architecture of DA-Platoon, vehicles can communicate through the VANET. Vehicles of one platoon share a unique DA-Platoon ID. According to the spatial position and functionalities, members in a platoon can be classified into four roles, namely, leader, relay, tail, and member.

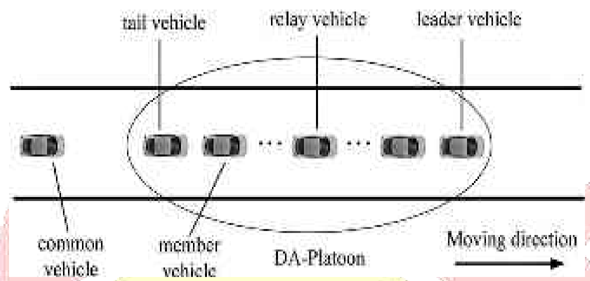


*fig.2* Formation of Platoon

1) Leader: The leader is the leading vehicle in the platoon. It is responsible for creating and managing the platoon, e.g. identifying and periodically broadcasting the DA-Platoon ID, deciding whether a vehicle can join the platoon and then assigning role to the vehicle, and determining whether a platoon shall be split or whether two platoons shall be merged into one.

2) Tail: The tail vehicle locates at the end of a platoon. It is responsible for communicating with the following vehicles, particularly the leader of the next platoon.

3) Relay: The relay vehicles act as data-forwarding nodes in a multihop VANET environment. In this way, the information from the leader can be efficiently disseminated to all vehicles in a platoon.

4) Member: Other member vehicles are regular vehicles that receive information from the relay and shall follow a specified driving strategy. With such a design, the topology of the VANET becomes simpler because a backbone is formed by the leader, relays, and tail. Moreover, the few relays can efficiently determine the transmission schedule of each vehicle in the platoon, which can significantly improve the reliability of VANET communications.

   Therefore, we can apply existing platoon management protocols to facilitate the implementation of the management strategy.

*D. Specification for a DA-Platoon Scenario*

1) Platoon Parameters: To facilitate further discussions, we let intraplatoon spacing be the distance between adjacent vehicles in the same platoon, and we let interplatoon spacing be the gap between the tail of a preceding platoon and the leader of the next platoon. Based on these definitions, we can define platoon parameters.
2) Knowledge of Traffic Information: To acquire traffic information, we assume that each vehicle is equipped with a Global Positioning System and other sensors that can collect all needed local information from neighbors, including acceleration, velocity, location, direction, etc. In addition, ACC and VANET components are equipped on each vehicle.

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3) VANET Communication Model: From a physical-layer perspective, many factors may affect VANET connectivity, such as transmission range, transmit power, data rate, interference, etc. As an initial step of our investigation, in this paper, we only consider the transmission range as the major impact on VANET connectivity. Moreover, to reliably deliver data among vehicles, we deem that the topology of the VANET shall be maintained even under disturbances.
4) Platoon Driving Strategy: Due to strong interaction among adjacent vehicles within the same platoon, the most common vehicle mobility model is the car-following model, which can effectively describe ACC-equipped platoon dynamics [13].

## II. ARCHITECTURE

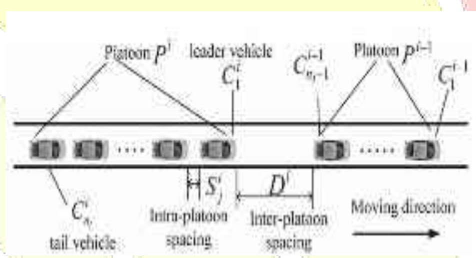


*fig.3* Platoon Dynamics

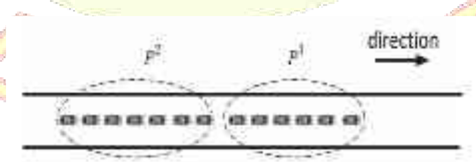


*fig.4* Platoon p1 and p2 with small intra-platoon Spacing

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| NOTATIONS | EXPLANATION |
|---|---|
| $P^i$ | Platoon 2 before forming |
| $P^{i-1}$ | Platoon 1 before forming |
| $C^i_1$ | Leader vehicle of platoon 2 |
| $C^{i-1}_1$ | Leader vehicle of platoon 1 |
| $C^{i-1}_{ni-1}$ | Tail vehicle of platoon 1 |
| $C^i_{ni}$ | Tail vehicle of platoon 2 |
| $D^i$ | Inter-platoon spacing |
| $P^1$ | Platoon 1 after forming |
| $P^2$ | Platoon 2 after forming |
| $S^i_j$ | Intra-platoon spacing |

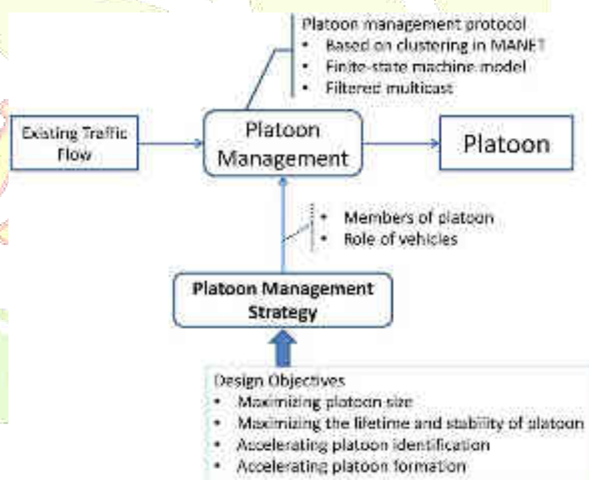


*fig.5* Platoon Management Strategy

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## IV. EXPECTED OUTPUT

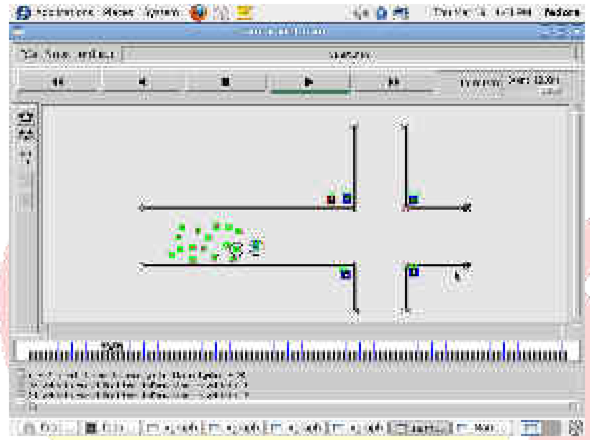

*fig 6.*Accident occurring between two VANET Enabled-vehicles in a LAN

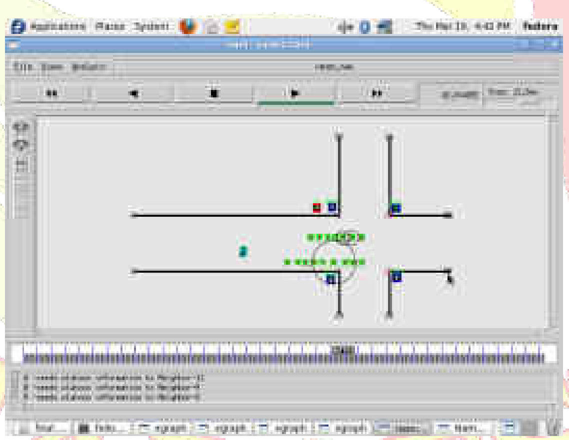

*fig 7.* VANET Enabled-vehicles communicating with the RSU enabling V2R interaction

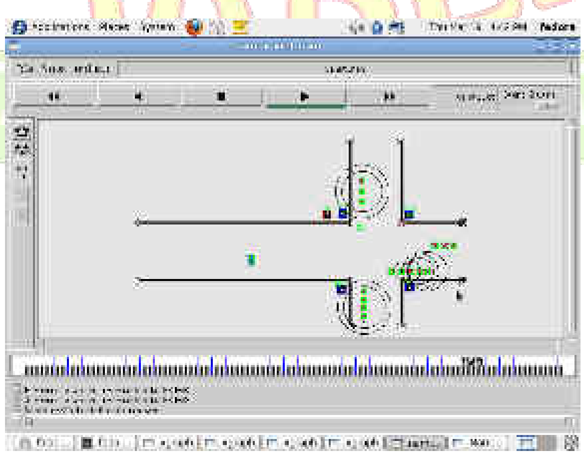

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*fig 8.*Avoiding the malicious attackers message by building up the trust authority to remove fake vehicle

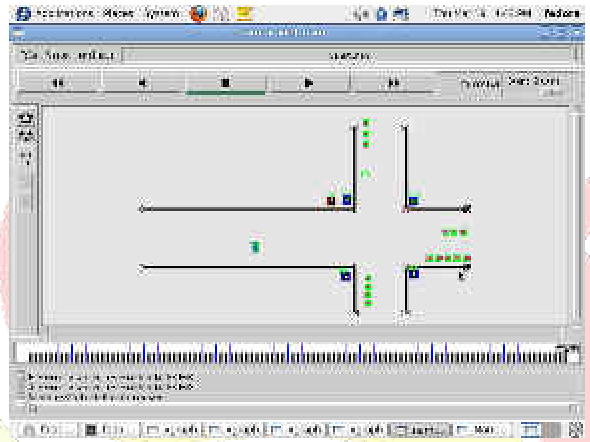

*fig 9.*Fake device license is removed and the vehicles moving further forming platoon

## V. CONCLUSION

In this paper, we have investigated the dynamics of a VANET-enabled platoon under disturbance. In particular, we first proposed a novel DA-Platoon architecture, in which both platoon dynamics and VANET behaviors are taken into consideration. With a specific design of the DA-Platoon architecture, we have analyzed the intraplatoon dynamics, and we have identified the effectiveness of the proposed driving strategy to build up an RSU as a proposed system and also to achieve parallel movement of platoon. However malicious attackers can also pass fake messages, which can be overcome using our concept of trust authority. Next, to mitigate the adverse effects of traffic disturbance, we have also designed a novel driving strategy for the leading vehicle of DAPlatoon, with which we can determine the desired interplatoon spacing. Finally, extensive simulation experiments have been conducted, which validate our analysis and demonstrate the effectiveness of the proposed driving strategies.

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