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A New Method for Reconfiguring Vehicle Platoon

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***Abstract*—Multiple vehicles make a line in platooning. Also information about driving operations is shared in the vehicles and the vehicles perform same actions. An ordinary driver controls the front vehicle in platooning. Information of driving operations by the ordinary driver is transmitted to following vehicles. Then auto-driving in following vehicles becomes possible. Recently, working long hours and shortage of manpower become big issues in the logistics industry. Platooning could solve these issues. In platooning, the second and subsequent vehicles are driven by automatic driving. The load on the drivers of the second and subsequent vehicles can be reduced. It is also expected that platooning reduces traffic congestion and carbon dioxide emissions. Currently, a platoon can be formed in a restriction where vehicles that have been set in advance only can join the platoon. In order to resolve the restriction, this paper proposes a new method for reconfiguring vehicle platoon in motion, which consists of four functions – forming a new platoon, platoon merging, dividing a platoon, and seceding from a platoon. Then, this paper shows simulation results to clarify what traffic situations where the proposed method could work well or not are.**

Keywords-component; Platoon; Auto-Driving; ITS; Vehicle-to-Vehicle communication; Simulation

I. INTRODUCTION

Technologies about auto-driving makes a lot of progress recently. Platooning is the one of the auto-driving technologies. In platooning, vehicles form a line. The line is called as a vehicle platoon or a platoon. Then vehicles in a platoon are connected by a wireless communication network. In platooning, an ordinal driver controls a lead vehicle of a platoon. However, the second and subsequent vehicles follow the lead vehicle automatically in platooning. Drivers in the second and subsequent vehicles have nothing to do except starting a vehicle, forming the platoon, and dealing with any emergency.

It is the first merit of platooning that the load of drivers can be reduced. Also platooning has the following merits.

The second merit is to alleviate traffic congestion. In a case of platooning, each vehicle could become closer than a case of vehicle driven by humans. It is because vehicles can sense inter-vehicle distance in all time in platooning. It could make create road space that each vehicle becomes closer.

The third merit is that fuel efficiency becomes better. As we mention above, each vehicle could become closer. So closing inter-vehicle distance can reduce wind drag for following vehicles. Then fuel efficiency becomes better.

In 2013, a demonstration experiment [1] was performed and achieved success. In the demonstration experiment, four vehicles made a platoon, where vehicles kept speed 80km/h and inter-vehicle distance less than 10(m) without human vehicle operations for second, third, and fourth vehicles.

In 2016, European truck platooning challenge [2] was performed and achieved success. In the European truck platooning, a platoon consisted of vehicles from many European vehicle manufacturers and the platoon travelled among a several European countries.

As we mention above, there exist merits in current platooning, in which the source and destination of each vehicle is the same. However, current platooning has the following disadvantage. To make a platoon, we have to make a plan of the platoon in advance. It is impossible to reconfigure any vehicle platoon while vehicles are in motion.

In this paper we propose a new method for reconfiguring vehicle platoon while vehicles whose sources and destinations are not necessary same are in motion. In the method, vehicles communicate with each other, check each destination of vehicles, and reconfigure vehicle platoon. Reconfiguring the vehicle platoon consists of forming a new vehicle platoon if some conditions are satisfied, platoon merging, dividing a platoon, and seceding from a platoon. The more vehicles in motion become a platoon dynamically, the more the merits of vehicle platooning can be enhanced.

II. STANDARD PLATOONING

Before we mention vehicle platooning, we introduce some technical terms and assumptions.

A *lead vehicle(LV)* is the first vehicle in a platoon. Each vehicle has only one lead vehicle.

A *tail vehicle(TV)* is a vehicle that is at the tail of a platoon.

A *following vehicle(FV)* is a vehicle that is a part of platoon except a lead vehicle. A tail vehicle is one of following vehicles.

Assumption 1: LV, TV, and FV have a wireless communication function capability such that messages are sent and received between vehicles.

Assumption 2: TV and FV have an auto cruising function, which keeps inter vehicle distance and so on.

In standard platooning [3], vehicles, which a platoon will consists of, gather in some place (ex. parking lot.) Before forming a platoon, each vehicle is driven by human. And the vehicles form a line. Then the vehicles are connected with each other by wireless communications. So a platoon is completed.

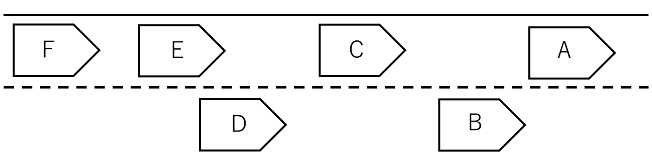
After the platoon is completed, LV of the platoon starts to a destination and FVs invoke auto-cruising function to follow the LV while keeping some inter vehicle distance automatically. As we have mentioned in Section 1, platooning has beneficial merits. However, it is impossible that two vehicles in motion form a new platoon, even if destinations of two vehicles are same.

III. A NEW METHOD FOR RECONFIGURING VEHICLE PLATOON

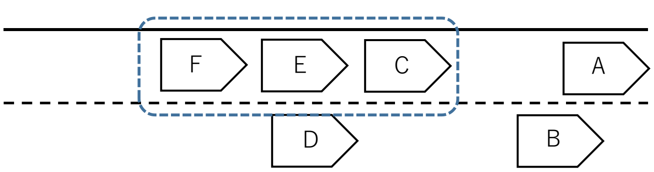
A. *Example of forming vehicle platoon*

In this section we would like to propose a new method for reconfiguring vehicle platoon. This method enables that vehicles in motion form new platoons dynamically, two platoons merge into a new platoon, and a vehicle secedes from a platoon. Hereinafter we call such the above method as *proposed method*. Before we explain the proposed method, we would like to introduce the following assumption.

Assumption 3: All vehicles have a car-navigation system. Then each vehicle repeats to search a route for a destination of the vehicle with regularity.



(a) Vehicles in motion before forming vehicle platoon



(b) Vehicles in motion after forming vehicle platoon

Figure 1. Forming a new Platoon

We will show an example of forming vehicle platoon. See Figure 1. There exist 6 vehicles in a street. All vehicles go to right. As we have described at Assumption 1, these vehicles can communicate with V2V communications. In Figure 1(a), all vehicles communicate with each other. First, all vehicles know destinations of each vehicle. Then, vehicles C, E, and F know that vehicles C, E, and F will go to the same destination. In the proposed method, vehicles C, E, and F in motion can form a new platoon as shown in Figure 1(b). As a result, vehicles C, E, and F can obtain the merits of platooning.

The proposed method for reconfiguring vehicle platoon consists of the following four functions – forming a new platoon, platoon merging, dividing a platoon, and seceding from a platoon. Different from the standard platooning, the originality of the proposed method is to dynamically reconfigure vehicles platoon in motion using the following four functions.

B. *Forming a new platoon*

Suppose the following situation. Vehicle A is followed by vehicle B, the destination of vehicle A is close to that of vehicle B. Vehicle A will pass close by a destination of vehicle B. In this case, vehicles A and B can form a new platoon, the platoon, and the platoon moves on to a destination of vehicle A. When the platoon comes close to the destination of vehicle B, vehicle B secedes from the platoon and goes to the destination of vehicle B. If this case happens, vehicle B would obtain merits of platooning.

Here, we introduce the following conditions for forming a new platoon.

Platooning condition S1: Vehicle A and vehicle B can communicate with each other by vehicle-to-vehicle communication directly.

Platooning condition S2: Vehicle A passes through some point X where the distance between the point X and a destination of B is less than a given threshold *Th*.

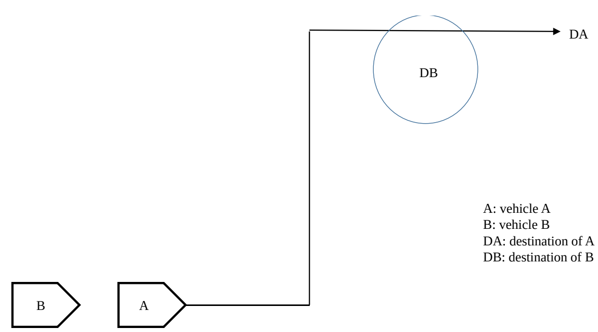


Figure 2. Platoon condition S2

See Figure 2. A line with arrow means driving route of vehicle A. Then, the center of a circle is a destination of vehicle B and the radius of the circles is the threshold *Th* in platoon condition S2. So, vehicles A and B in Figure 2 satisfies platoon condition S2, then vehicles A and B form a new platoon.

Procedure for forming a new platoon

Trigger of this procedure:
Vehicle A is followed by vehicle B. And no vehicles exist between A and B.

(1)If platooning condition S1 is satisfied between vehicle A and vehicle B, vehicle B sends a forming platoon request message to vehicle A with information about a destination of vehicle B.
(2)When vehicle A receives the forming platoon request message, vehicle A checks the platooning condition S2.
(3a)If the platooning condition S2 is not satisfied, vehicle A sends a reject message to vehicle B and this procedure ends.
(3b)Or if the platooning condition S2 is satisfied, vehicle A sends an accept message with information about driving route information of vehicle A to vehicle B.
(4)When vehicle B receive the accept message, vehicle B stores driving route information of vehicle A as driving route information of the platoon. Then vehicles A and B form a new platoon.

C. *Platoon merging*

Suppose that platoon P1 is followed by platoon P2, and no vehicles between P1 and P2. When P1 and P2 become closer, P1 and P2 try to merge.

Procedure for platoon merging

Trigger of this procedure:
Platoon P1 is followed by platoon P2. And no vehicles exist between P1 and P2.

(1)If platooning condition S1 is satisfied between the TV of P1 and the LV of P2, the LV of P2 sends a platoon merging request message to the TV of P1 with information of a destination of P2(which is same as a destination of the LV of P2).
(2)When the TV of P1 receives the platoon merging request message, the TV of P1 checks the platooning condition S2.
(3a)If platooning condition S2 is not satisfied, the TV of P1 sends a reject message to the LV of P2 and this procedure ends.
(3b)Or if the platooning condition S2 is satisfied, the TV of P1 sends an accept message with information about driving route of P1 to the LV of P2. (Note that driving route information of a LV of platoon P is shared in platoon P.)
(4)When the LV of P2 receives the accept message, the LV of P2 requests to all FVs of platoons P2 to update driving route information to driving route information of P1. Then all vehicles of platoon P2 become the FVs of platoon P1.

The above is description about two platoons merging. A platoon and a vehicle merging is performed in a similar manner as two platoons merging.

D. *Dividing Platoon*

Suppose the following case. Platoon P is passing an intersection with a green signal. However, the green signal turns to a red signal. Then, some vehicle and its subsequent vehicles in platoon P stop at the intersection.

In such a case, a dividing platoon procedure is performed as follows.

Dividing platoon procedure
Trigger of this procedure:
For some reason (i.e. red signal), FV X of platoon P stops.
(1)The FV X of the platoon P sends a dividing platoon message with information of platoon P to a vehicle which is subsequent to the FV X and the FV X becomes out of the platoon P.
(2)When a vehicle receives a dividing platoon message with information of platoon P, the vehicle checks whether the vehicle is a member of platoon P.
(3a)If the vehicle is not a member of platoon P, the vehicle does nothing.
(3b)Or if the vehicle is a member of platoon P, the vehicle relays the dividing platoon message to the subsequent vehicles and becomes out of platoon P.

Finally, all FVs which are subsequent to FV X become vehicles which do not belong to any platoons. However, these vehicles would belong to the same platoon again. Otherwise, the divided subsequent vehicles would become a new platoon.

E. *Seceding from a platoon*

Even if a FV is in platoon P, a destination of the FV is different from a destination of a LV of P in general. So the FV has to secede from platoon P when the FV approaches the destination of the FV.

Seceding from a platoon procedure
Trigger of this procedure:
FV X is in Platoon P. The distance between current position of FV X and a destination of FV X becomes less than the given threshold *Th* in platoon condition S2.
(1)FV X sends a seceding message with information of platoon P to a vehicle which is subsequent to FV X, becomes out of the platoon P, and runs to the destination of FV X.
(2)When a vehicle receives a seceding message with information of platoon P, the vehicle checks whether the vehicle is a member of platoon P.
(3a)If the vehicle is not a member of platoon P, the vehicle does nothing.
(3b)Or if the vehicle is a member of platoon P, the vehicle relays the dividing platoon message to the subsequent vehicles and becomes out of platoon P.

In this case, all FVs which are subsequent to FV X become vehicles which do not belong to any platoons.

IV. EVALUATION

We expect that the proposed method would create many platoons dynamically. However, due to the dynamic feature of the proposed method, it is unclear what traffic situations where the proposed method could work well or not are. In order to clarify traffic situations where the proposed method works well or not, we have performed simulation experiments and have measured platoon participation rate. Platoon participation rate (PPR) is defined as the following (1)

$$PPR = NPV/NV \qquad (1)$$

where NPV is the number of vehicles which are member of any platoon and NV is the number of all vehicles.

A. Parameters of simulation experiments

In order to reflect various traffic situations, we have prepared four kinds of parameters.

The first parameter is about shapes of road map. We have prepared three kinds of shapes, which are 4x4 grid, 5x5 grid, and 6x6 grid where 1x1 grid is 300(m)x300(m).

The second parameter is about the number of vehicles. We have prepared two kinds of the number of vehicles, which are 100 vehicles and 200 vehicles. Therefore, a parameter pair of 100 vehicles and 6x6 grid means a situation of low vehicle density, and a parameter pair of 200 vehicles and 4x4 grid means a situation of high vehicle density.

The third parameter is about itinerary type. In the first itinerary type, each vehicle chooses a source and a destination randomly unless the source and the destination is same. Initial driving route is the shortest path between the source and the destination. In the second itinerary type, each vehicle chooses a source randomly except four corners of road map. And each vehicle chooses a destination randomly among four corners of road map. Initial driving route is the shortest path between the source and the destination. The second itinerary type reflects traffic situation where there exist a few famous spots which people want to go to. On the other hand, the first itinerary type reflects traffic situation where there exist no famous spots like residential zone.

The last parameter is about threshold *Th* in platoon condition S2. We have prepared two kinds of threshold *Th*, which are 300(m) and 600(m).

Other simulation factors are as follows.

TABLE I. SIMULATION FACTORS

Velocity of vehicles	Random between 0—60km/h
Simulation time	500(sec)
Wireless communication range (platoon condition S1)	50(m)
Number of simulation trials	5 for each parameter combinations

B. Results

Figures. 3 - 8 show the average time when PPR is in some section.

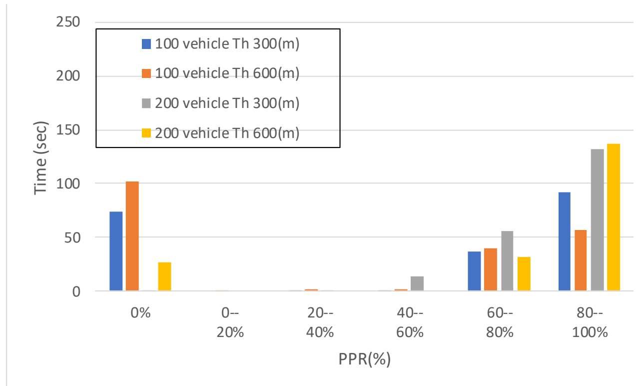


Figure 3. Average time of PPR sections for 4x4 grid and 1st itinerary type

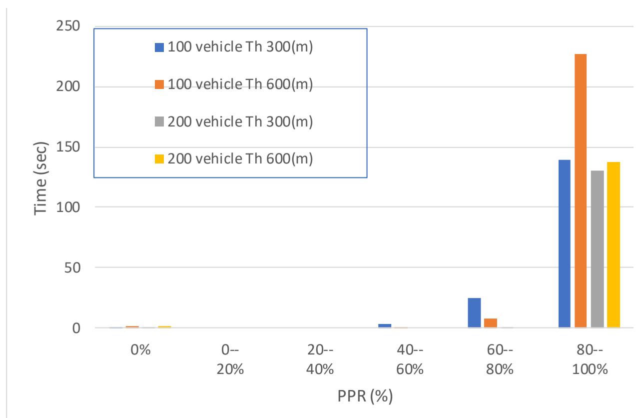


Figure 4. Average time of PPR sections for 4x4 grid and 2nd itinerary type

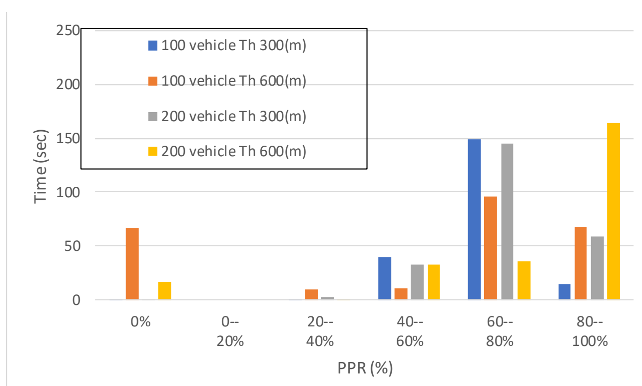


Figure 5. Average time of PPR sections for 5x5 grid and 1st itinerary type

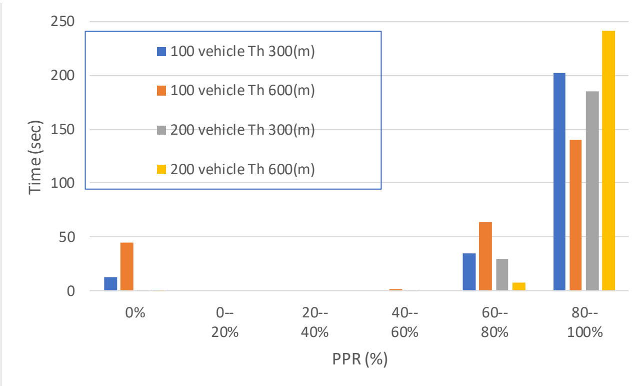


Figure 6. Average time of PPR sections for 5x5 grid and 2nd itinerary type

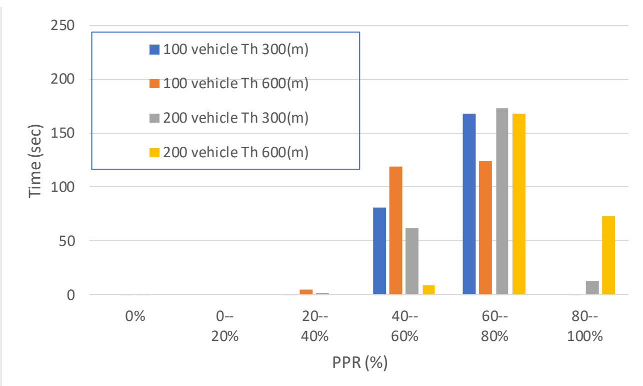


Figure 7. Average time of PPR sections for 6x6 grid and 1st itinerary type

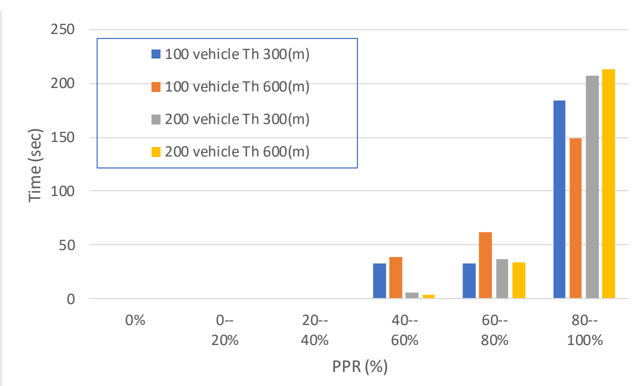


Figure 8. Average time of PPR sections for 6x6 grid and 2nd itinerary type

See Figure 3. The most left bar means that the average time when PPR is equal to 0% is 73(sec) in simulations for a parameter combination (4x4 grid, 1st itinerary type, 100 vehicles, *Th* 300(m)). Also, the most right bar means that the average time when PPR is in a section over 80% is 137(sec) in simulations for a parameter combination (4x4 grid, 1st itinerary type, 200 vehicles, *Th* 600(m)).

C. *Consideration*

We have planned that simulation time of experiments is 500(sec). However, all vehicles arrive at each destination before simulation time becomes 500(sec). So the total time of average time is not equal to 500(sec).

See Figures 4, 6, and 8. They are results on 2nd itinerary type. In these results, an average time of a section over 80% are longest. In simulation experiments about 2nd itinerary type, each vehicle chooses a destination among four corner of the road map. So probability where destinations of two adjacent vehicles are same is 25%. Moreover, as simulation time goes on, some group of vehicles gather to one of the corner of the road map and other group gather to another corner of road map. So probability, where a vehicle meets other vehicles where destinations are same, becomes high.

Next, we consider effects on density of vehicles. Here we focus on results of 1st itinerary type. Compare Figure 7 to Figure 3 or Figure 5. Average time when PPR is over 80% is lowest and average time when PPR is between 40% and 60% is highest. Conversely compare Figure 3 to Figure 5 or Figure 7. Average time when PPR is over 80% is highest and average time when PPR is between 40% and 60% is lowest. This shows that the vehicle density influenced the reconfiguring vehicle platoons.

In the simulation experiments, we could not find difference due to the difference in parameters threshold *Th* in platoon condition S2.

V. Conclusion

In this paper, we have proposed the dynamic method for reconfiguring vehicle platoon. And we have showed the results of simulation experiments for evaluating the proposed method of reconfiguring vehicle platoon, which consists of forming a new vehicle platoon if some conditions are satisfied, platoon merging, dividing a platoon, and seceding from a platoon. The results of simulation experiments implies that the more routes between pairs of a source and a destination of vehicles are overlapped, the more the dynamic method for forming vehicle platoon could work well. Dynamic reconfiguration of vehicle platoon proposed in this paper suggests a possibility to open a venue for realizing a new service of MaaS (Mobility as a Service).

In future works, we will perform simulation experiments which reflect real traffic situation to extensively analyze properties of the proposed method for reconfiguring vehicle platoon.

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