Overtaking Action Control Method Based On FCFS Policy Considering CO2 Emissions

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ABSTRACT

Platooning is highly expected as a solution for the environmental issues. It is supposed to bring good effect to the platoon member themselves. However, it sometimes prevent surrounding vehicles from overtaking smoothly. We name the problem the overtaking conflict and propose an overtaking action control method in order to solve the overtaking conflict. The proposal is based on the token-based distributed mutual exclusion algorithm and consists of four phases. The proposed method is evaluated through the computer simulation in terms of the average speed and the amount of CO2 emissions. The simulation environment is composed of the network simulator and the traffic simulator. Both two simulators execute in parallel exchanging calculation results at every time step. We precisely evaluate and show the advantages of the proposal.

Keywords: Platooning, FCFS, Distributed Mutual Exclusion

1 Introduction

One of the cooperative driving application, platooning is widely discussed [1]–[3]. Platooning is a form of driving, multiple trucks drive close to each other, making tandem array. We especially focus on the truck platooning on the expressway in the suburb. Truck platooning aims four things; energy saving of trucks due to reducing air resistance via short inter-vehicular distance, enhancing the road capacity due to the short inter-vehicular distance, alleviating fatigue of drivers due to automatic driving and enhancing the safety because of reducing the difference of each truck's velocity. According to a report, platooning could reduce 15% of the CO2 emission in case that the distance between the trucks is 4m [2]. However, Platooning possibly causes a problem, named the overtaking conflict. The conflict sometimes makes vehicles unnecessarily accelerate and decelerate. Consequently, it causes extra CO2 emissions.

In order to solve the problem, we apply the distributed mutual exclusion algorithm into the overtaking conflict and bring the FCFS policy to the overtaking action. Its efficiency is briefly introduced in [4]. We improve the original method and implement the application on the network simulator and the traffic simulator. The proposed method is precisely evaluated executing both simulator in parallel, compared to the existing methods. We adopt the average speed and the amount of CO2 emissions as evaluation figures.

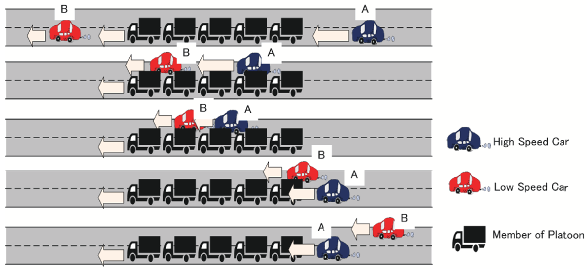

Figure 1: Overtaking Conflict: High Speed Vehicle Decelerate

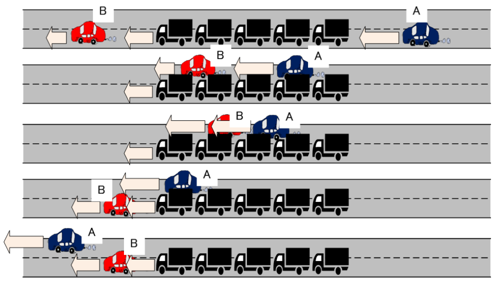

Figure 2: Overtaking Conflict: Low Speed Vehicle Accelerate

The rest of this paper is organized as follows; we define and describe about the overtaking conflict in Section 2. Section 3 reviews the related work and adapt the algorithm to the overtaking conflict situation. Section 4 introduces the proposed method and explain the details of it. In Section 5, we evaluate our proposal in terms of the carbon dioxide emissions and present the result. Finally, Section 6 concludes this paper.

2 Overtaking Conflict

According to a specific project as an example [2], they assume that the platoon drives on the express way. Ordinary vehicles could drive in any lane on the express way and the platoon would drive in the designated lane with ordinary cars. Every vehicle could know their own location with GPS devices and update it periodically. They are also able to communicate with each other with inter vehicular communication devices. Particularly, the members of the platoon can organize and join ad-hoc networks.

Figures 1 and 2 depict about the problem, named the over-

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taking conflict. A low speed car, called A, is coming close to the platoon from the front side and a high speed vehicle called B is coming from the back side. Roads consist of two lanes each way and one lane is occupied by the platoon, so there is one lane available for the two cars. Hence, vehicle B cannot overtake vehicle A and we call it the overtaking conflict. In order to solve this conflict, vehicle A has to be accelerated to keep driving right before the platoon or vehicle B has to be decelerated to keep driving right behind the platoon. Considering about the case that vehicle A is accelerated, after vehicle A change lanes, vehicle B gets enough space to overtake vehicle A. Then, vehicle A is decelerated again and be overtaken by the platoon.

We describe this case in detail. The overtaking conflict brings various bad effects on vehicles. Either vehicle A or B has to be accelerated or decelerated unexpectedly, so not only their CO2 emission efficiency becomes worse but also it prevents smooth traffic flow. Moreover it has a bad effect in terms of the safety. It means overtaking conflict causes the opposite things of what the platoon originally purposed. Some example says that the platoon is supposed to consist of 3 to 8 trucks. That is its length is supposed to be more than 50 meters. We can easily guess that the overtaking conflict would happen frequently and this problem should be solved.

3 Distributed Mutual Exclusion

The reason of the overtaking conflict is that two or more vehicles are trying to overtake at the same time and they are not able to notice about each other in advance. The distributed mutual exclusion algorithm is adapted to this situation in order to avoid the conflict. In that case, we assign particular part of lane, where is next to the platoon, to a critical section.

Generally speaking, distributed mutual exclusion algorithms are classified into two categories, one is permission-based algorithm and the other is token-based algorithm [5].

3.1 Permission-Based Algorithm

Permission-based algorithm is introduced by Ricart et al.[6]. For instance, there are multiple processes called A, B, C and so. When process A wants to enter the critical section, process A sends requests to all of the rest to get permission. Only when process A gets permissions from all of them, process A is allowed to enter the critical section. Focusing on process B, in case it does not want to enter the critical section, process B replies to process A as soon as process B gets a request from process A. On the other hand, in case process B wants to enter the critical section, same as A, process A and B compares their requests' time-stamp, then, a process sends a request earlier can get permission from the other. Some other algorithms use quorum or quorum group and choose a process by vote.

3.2 Token-Based Algorithm

The token-based algorithm uses token. There is only one token and only one process which has the token can enter the critical section. The token goes around from a process to another process, a process finds and gets the token when it wants to enter the critical section. Token-based algorithms have some advantages, most important one is that it guarantees about the dead-rock problem and the starving problem through the simple procedure. Furthermore, token-based algorithms usually require fewer amounts of messages, compared to permission-based algorithms. In the token-based algorithms, processes are typically supposed to organize a ring structure or a tree structure[7]. For example, in case it is tree structure, when process B needs to get the token while process A is having the token, the time for the token to reach from process A to process B depends on the each location. In a worst case situation, it takes too much time to enter the critical section. Ortiz et al. introduced a method which reduce the amount of messages by using multicast [8], [9].

However, token-based algorithms include two problems [10]. One is ensuring the compatibility between fair schedule and the small amount of messages. The other is complicated procedure when processes lose the token and reissue it, which is especially called reissue algorithms. The reissue algorithm is, in other words, the algorithm for choosing actor who reissue the token [11]. It is widely discussed and a lot of algorithms are proposed, some of them are distributed processes [12].

3.3 Comparison

The reason of giving the distributed mutual exclusion algorithm to the overtaking conflict is as follows. The permission-based algorithms require a vehicle to get the permission from all vehicles within the platoon's communication range when it needs to enter the critical section. To take communication range into account, members of the platoon have to forward messages from a vehicle sending a request to the other. In addition, the critical section is right next to the platoon, so the tree structure whose root is assigned to the platoon is preferred. At a conclusion, the token-based algorithm is better suited for this situation than the permission-based algorithm.

However, it is not simple to apply the token-based algorithm in the overtaking conflict. We propose and explain how we realize the action control in the next section.

4 Overtaking Action Control Method

In this section, we propose an overtaking priority management method based on the distributed mutual exclusion algorithm in order to solve the overtaking conflict. Our proposal is based on the token-based distributed mutual exclusion algorithm. One member of the platoon, called the master truck, manages and controls the token. The master truck originally controls and manages its own platoon and platoon members. We define that a part of a lane which is next to the platoon, is the critical section. The master truck would allow one of all vehicles having the token to enter into the critical section.

Our proposal consists of 4 phases; the driving alone phase, the access phase, the overtaking phase and the separation phase as shown in Figure 3. Members of the platoon and surrounding vehicles behave in each phase as shown in Figure 3. Briefly

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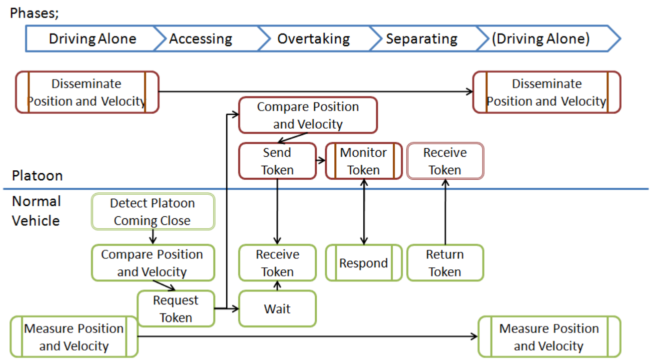

Figure 3: Phase and Process of Proposal

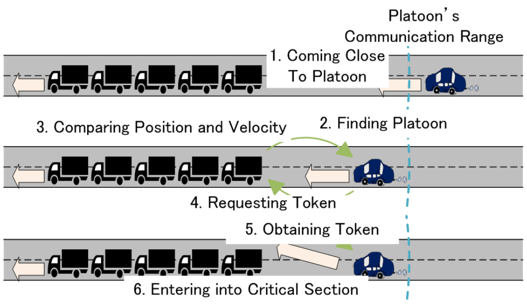

Figure 4: Actions in Access Phase

speaking, vehicles try to get a token when vehicles come close to the platoon, the master truck sends the token to one of them. Then, the vehicle that gets the token, starts to overtake the platoon. After finishing overtaking, the vehicle returns the token to the master truck. Trucks and vehicles repeat those processes every time overtaking is about to happen. We explain about each phase in the following sections.

4.1 Driving Alone Phase

In the beginning, the master truck has the token. It announces its own position and velocity by broadcast, using communication devices and it sends packets with the platoon filter [13]–[15]. The platoon filter is a kind of identifier and members can manage the filter by themselves. We assume that every vehicle has communication devices and they are able to communicate with each other [16], [17]. It is also assumed that they can know their own position and velocity with GPS devices. It means that vehicles would know neighbors position and velocity. Without loss of generality, we assume that a number of the lane where the overtaking conflict could happen is one.

4.2 Access Phase

Figure 4 shows actions in the access phase. This phase is from when a vehicle comes close to the platoon till the vehicle enters the critical section. First, a vehicle detects the platoon when it drives close to the platoon because the platoon periodically announces its own position. Second, the vehicle compares the position and velocity to the platoon. The vehicle tries to get the token from the master truck in case the vehicle is about to overtake the platoon. After the vehicle sends a request, it starts to wait for the token. The master truck also compares the position and velocity as soon as it gets the request. After the truck confirms the vehicle is actually coming close to the platoon, the truck sends the token to the vehicle if the truck has the token. In case that two or more vehicles request the token, the truck lets the second and subsequent vehicles join the queue in order to hand the token according to the FCFS policy. At last, the vehicle gets the token and starts to enter the critical section, to overtake the platoon.

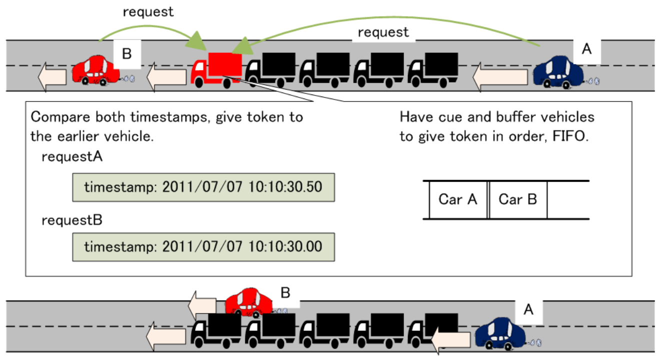

Figure 5: How to Solve Request Collision

Request Collision

The FCFS policy is adopted in our proposal method. The following is especially about the case that multiple vehicles send requests at almost the same time. Figure 5 shows how to solve this collision. A vehicle named A is coming from front side and another vehicle named B is coming from backside. Both of them send requests almost simultaneously but they are slightly different, request sent by vehicle A is a half second later than vehicle B. The master truck sends the token to vehicle B because the request sent by vehicle B is earlier. The earlier it requests, the earlier it would be allowed to enter the critical section. That is to say, our proposal is the first-come first-served service. The earlier vehicle, vehicle B, enters the critical section and overtaking the platoon according to the process as we described. The other vehicle, vehicle A, waits right behind the platoon until vehicle A gets the token. During it, vehicle A could join the platoon in order to reduce the carbon emission, sending request periodically. As soon as vehicle B returns the token, the master truck gives the token to vehicle A. At last, all vehicles that want to enter the critical section, can overtake the platoon and the overtaking conflict never happens.

4.3 Overtaking Phase

This phase starts when a vehicle enters the critical section and continues until it goes out of the critical section. There

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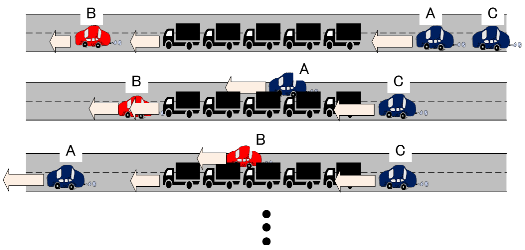

Figure 6: Accessing Two Vehicles from Same Direction

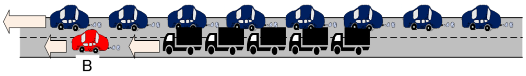

Figure 7: In Case Long Queue of Vehicles Are Overtaking

is one token relating to one platoon and only a vehicle having the token is allowed to overtake the platoon. The master truck remembers which vehicle is having the token from when it sends the token to the vehicle. During the overtaking phase, the master truck periodically sends packets to the vehicle and confirms where it is.

In addition, our proposal defines other two rules. First, when two vehicles drive close to the platoon together, even if those two vehicles drive in the same direction, only one vehicle is allowed to overtake at one time. The other, a platoon keeps at an enough distance from other platoons.

Handling Multiple Vehicles Driving Same Direction

Figure 6 depicts vehicles movement when 2 vehicles are coming from the same direction. Car A, B and C are coming close to the platoon at the same time as shown in Figure 6 and their request order is A, B and C. According to the process above, vehicle A starts to overtake. While vehicle A is overtaking, vehicle C is waiting at the right behind the platoon though vehicle C's movement never interferes A's. We have to consider the case a long queue of the vehicles are coming from one direction and another vehicle B is coming from the other direction, vehicle B is required to wait for a long time, possibly forever, as shown in Figure 7. This is the famous problem widely discussed, called the starving problem, and the proposal method is needed to avoid this problem. Thus, every vehicle has to wait until it gets the token without any exception, according to the fundamental rules we discussed before.

Distance between Platoons

During the overtaking phase, the distance between the platoons have to be more than a certain level, as shown in Figure 8. This is because the deadlock might happen if the distance is small. Suppose that the case 2 platoons are driving close to each other, first one is X and the other is Y. X is overtaking vehicle A, Y is being overtaken by vehicle B. At the time, vehicle A is coming close to platoon Y, so vehicle A requests platoon Y to send Y's token. Car B also requests platoon X.

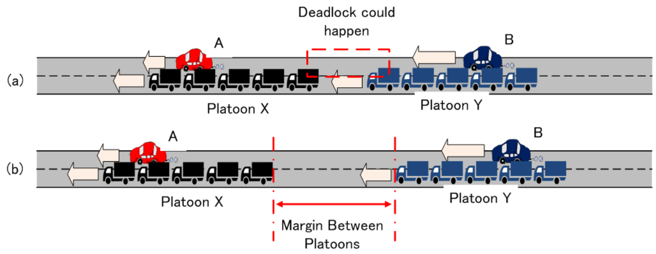

Figure 8: Distance between Platoons

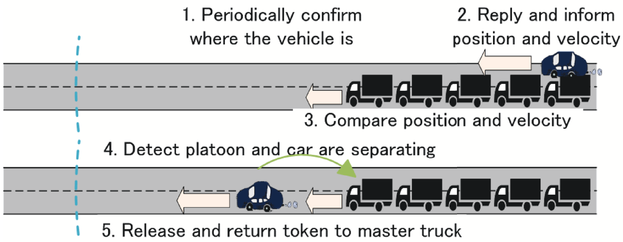

Figure 9: Process in Separation Phase

If the distance between platoons is small, both vehicle A and B cannot release the token and keep waiting to get the other token. Therefore, the platoons need to ensure a distance to let vehicle A and B to finish overtaking and to release the token. After both of them return tokens, vehicle A could get Y's token and vehicle B could get X's token. Of course vehicle B could overtake vehicle A. That is the reason why the distance between the platoons has to be big enough.

4.4 Separation Phase

Figure 9 shows actions through the Separation phase. This phase starts when a vehicle exits the critical section and goes until the vehicle gets out of the communication range. The platoon and the vehicle that is in the critical section keep periodically communicating with each other since the overtaking phase. The master truck also announces which vehicle is carrying the token and the token's timestamp at that time. Every time they communicate, both of them compare the position and velocity to each. Thus, they would notice they are separating away when the vehicle gets out of the critical section. As soon as either of them notices, the master truck requests the vehicle to return the token or the vehicle autonomously sends the token to the master truck.

Reissuing Token

Our proposal is based on the token-based algorithm, the exclusiveness is guaranteed through simple procedures as long as the token exists. However, once the token is lost, the complicated processes are needed to reissue the token. In this paper, the master truck is the one which reissues the token, and the master truck is also the one which administers what relating to the token.

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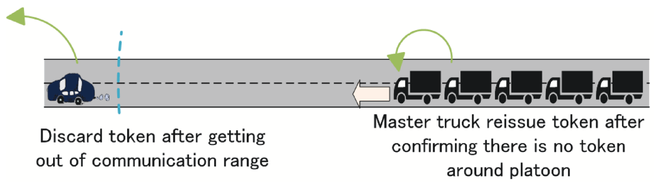

Figure 10: Discard and Reissue the Token

According to the existing studies, when they detect the lost of the token, they are required to choose the node that reissues the token, it is based on the leader selection algorithms. Those algorithms typically said that the chosen node has to achieve the consensus among all of nodes or all of nodes which possibly enter the critical section. After that, the chosen node discards the old token and reissues the new token.

Figure 10 shows how to reissue the token. In this paper, the loss of the token might happen when the vehicle having the token gets out of the communication range without returning the token to the master truck. In our proposal, the leader is chosen from the very beginning, it is the master truck. Moreover, the master truck is not required to gain consensus among vehicles. Instead of that, the master truck has to confirm that there is no token around the platoon, within the communication range, before reissuing the token. At the same time, the vehicle taking the old token from the communication range, has to discard the token after it comes not to be able to communicate with the master truck. Moreover, the token has its own timestamp and it denotes when it is issued or reissued. So, even if the old token has come back after the new token reissued, surrounding vehicles could know which token is the newest. The master truck and surrounding vehicles use the newest one as the token. Therefore, our proposal guarantees there is only one token existing.

Note that, our proposal could not guarantee in case radio communication device does not work. For instance, the case is that the device on the vehicle gets broken while the vehicle is along the way overtaking the platoon. The master truck misguidedly believes that there is no token around the platoon, unless other devices support; the sonar, driver's eyesight or so. If there are more than two tokens around the platoon at one time because of wrongly reissuing the token, multiple vehicles possibly enter the critical section at the same time. The bottom line is that we assume that radio communication devices would never get broken or that the master truck could somehow keep monitoring the token even when the radio does not work. However, the master truck is supposed to announce periodically about the token, surrounding vehicles could know if the management correctly works or not. Surrounding vehicles never misguidedly enter the critical section.

4.5 Vehicles Movement with Proposal

Figure 11 and 12 show the movement through the proposal. Figure 11 is in case that a low speed vehicle which initially driving in front of the platoon, gets the token first. Figure 12 is in case the other vehicle gets the token first. In both cases,

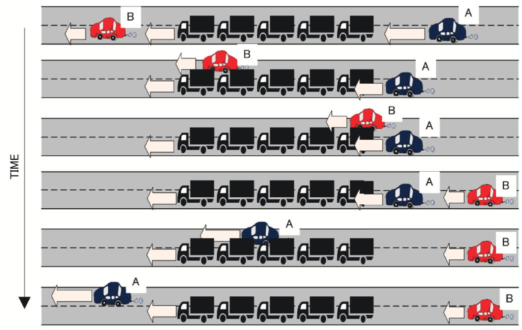

Figure 11: Vehicles Movement in Case Low Speed vehicle Gets Token First

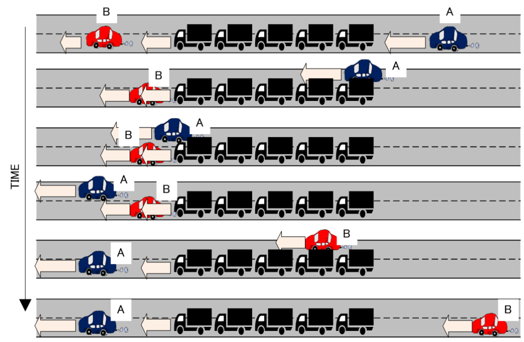

Figure 12: Vehicles Movement in Case High Speed vehicle Gets Token First

a low speed vehicle and a high speed vehicle do not need to be accelerated or decelerated more than necessary. Moreover, while the first vehicle is overtaking, the second vehicle is able to join the platoon and to reduce the carbon dioxide emission.

5 Evaluation

In this section, we report on simulations to evaluate the amount of CO2 emissions, the acceleration term of the emission model and the average speed of vehicles in order to show our proposal is efficient for surrounding vehicles. The simulations are conducted on Scenargie 1.4 [18] and MATES (ADVENTURE_Mates Version 0.11 beta) [19]. Scenargie is a network simulator and MATES is a traffic simulator, both simulators run simultaneously. On one hand, Scenargie gets node positions information according to the MATES calculation results at every simulation time step in order to simulate radio communication between nodes. On the other hand, MATES gets communication information according to the Scenargie calculation results at every simulation time step in order to simulate nodes mobility.

We employ the carbon dioxide emission model introduced by Oguchi et al.[20] denoted as follows:

$$E = 0.3K_C T + 0.028K_C D + 0.056K_C \sum_{k=1}^{K} \delta_k (v_k^2 - v_{k-1}^2), \tag{1}$$

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Table 1: Simulation Conditions

Model	Parameter Name	Value
Road Model	Road Length	10.0km
	Number of Lanes	2(One Way)
	Dedicated Lane for Platoon	1
	Lane Width	3.5m
Platoon Model	Number of Platoon Members	3
	Distance between Platoon Members	4.0m
	Platoon Member Length	12m
	Platoon Member Width	2.5m
	Platoon Member Height	3.8m
	Platoon's Expected Speed	80 km/h
	Volume of Platoon Inflow	60 Platoon/(lane·hour)
Non-Platoon Model	Volume of Inflow	Various
	Low Speed Vehicle's Expected Speed	60 km/h
	High Speed Vehicle's Expected Speed	100 km/h
	Vehicle Length	4.7m
	Vehicle Width	1.7m
	Vehicle Height	1.5m
Network Protocol Model	Radio Communication Standard	802.11p
	Frequency	5.9GHz
	Modulation	OFDM(QPSK1/2)
	Transmission Speed	6Mbps
	Bandwidth	10MHz
	Transmission Power	20dbm
	Antenna Directivity	omnidirectional
	MAC	CSMA/CA
	Propagation Model	ITU-R P.1411

where E is the amount of carbon dioxide emissions, specifically it is equivalent, K_C is the conversion coefficient from the fuel consumption to the carbon dioxide emissions, T denotes the trip time, D is the trip distance, δ_k is dummy variable, equals 1 if the vehicle is accelerating otherwise equals 0, and v is the velocity.

We evaluate the scenario which platoons and other vehicles drive on the straight road which consists of two lanes. Vehicles which are not platoon members are two kinds of vehicles, one drives at a low speed, 60 km/h. The other drives at a high speed, 100 km/h. Every vehicle is supposed to drive at the expected speed as long as possible. Both inflows are same amount and they are variable. Platoons inflow at fixed amount in each scenario and it is 60 platoons/(lane·hour). Platoons and vehicles inflow from one edge of the express way and go out from the other edge. Every vehicle supposed to have a radio communication device and they exchange beacon messages at every 100 msec. In proposed method, the information piggybacks on beacon messages.

We compare three overtaking action methods; two distance based overtaking action methods and the proposal method. The distance based overtaking action methods are assumed as normal drivers actions. Those are that one vehicle which drives at a high speed changes lanes when it gets within a certain distance of another vehicle or platoon which drives at a lower speed, in order to overtake the low speed vehicle. One of the threshold distance is 150m and the other is 70m. The other parameters are given in the table 1.

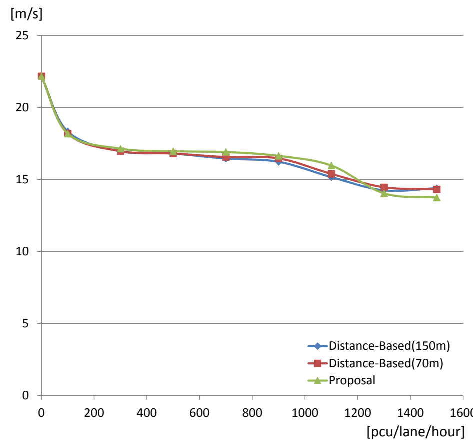

Figure 13: Average Speed

Figure 13 shows the average speed of vehicles. In every method, as the vehicle density increases, the average speed gradually decreases. Moreover, there is almost no difference between those three methods, so that the proposal does not prevent traffic flow compared with the existing methods. They starts at about 22.2m/s, it is the platoon's expected speed. The average speeds go down little by little as the density goes up, and in case that the traffic jam almost happens, the average speed is about 14.5m/s, as is true with each method. It means the proposal never brings extra traffic jam.

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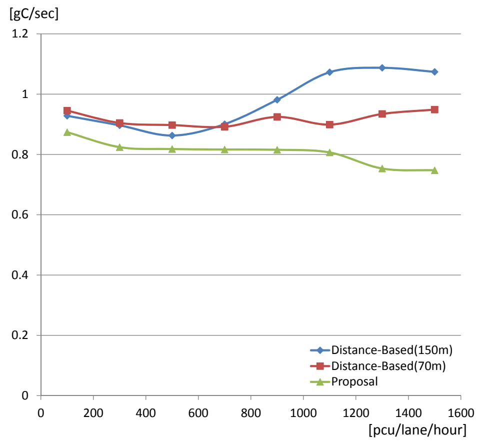

Figure 14: Average CO2 emissions per Trip Time

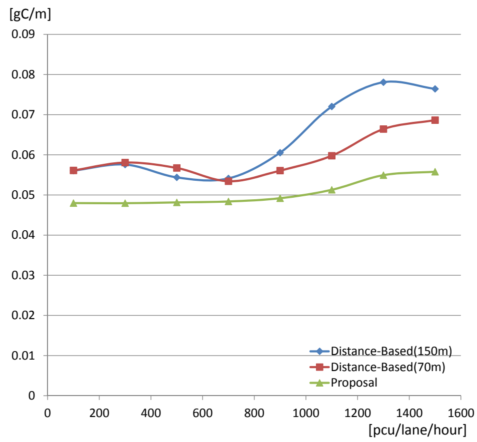

Figure 15: Average CO2 emissions per Trip Distance

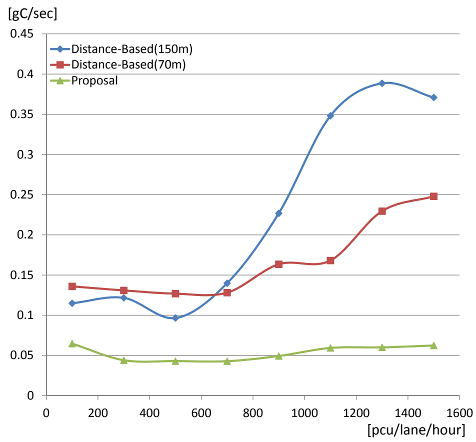

Figure 16: Average Acceleration Term per Trip Time

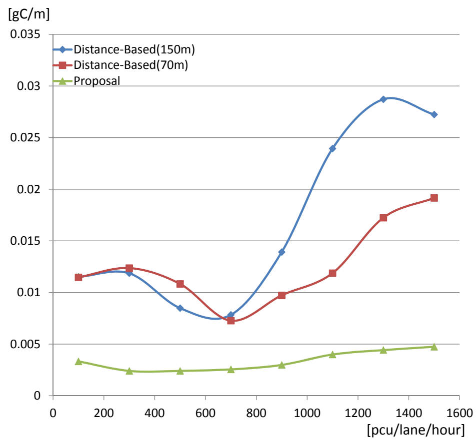

Figure 17: Average Acceleration Term per Trip Distance

Figure 14 is the average CO2 emissions per trip time and it is about non-platoon members. Figure 15 also indicates the average CO2 emissions per trip distance and it is also about non-platoon members. Two figures show the proposal method reduces CO2 emissions compared with the normal driver action. The difference becomes larger as the density increases. In case that the density is 100 per lane and hour, the proposal's time average is 30.42% less than the 150m distance based method's and the proposal's distance average is 27.00% less than the 150m distance based method's. The proposal's time average is also 21.24% smaller than 70m distance based method's and 18.73% smaller than 70m distance based method's.

Figure 16 is the time average acceleration term in the emission model (Equation 1). Figure 17 is the distance average acceleration term in the emission model. Two figures mean that these three methods' difference of CO2 emission amount is originally from the difference of acceleration term. That is to say the proposal method reduces overtaking conflict and reduces unnecessary acceleration.

Through the results of the above five figures, the proposed method decreases unnecessary acceleration and deceleration. So that the proposal decreases CO2 emissions and keeps vehicles drive smoothly. Because, according to the results, there is no difference in terms of the average speed and there is a certain improvement in terms of the acceleration. We can also say that, the more the vehicle density is, the more efficiently the proposal works. Consequently, at the maximum, the trip time average amount of CO2 emissions of the proposal is less by 21.24% than the comparison method, the trip distance average amount of CO2 emissions of the proposal is less by 18.73% than the comparison method.

6 Conclusion

Platooning is highly expected as an important role among ITS applications and widely studied in order to realize efficient carbon dioxide emissions. Besides realizing platoon, there are some challenges should be considered and solved in advance, important one of them is the overtaking conflict. According to one of the studies about platooning, it is supposed that one platoon consists of five trucks, it is more than 50 meters long. Thus, when a low speed vehicle is coming close from ahead of the platoon and a high speed vehicle is

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coming close from behind the platoon at the same time. We call this problem the overtaking conflict and it makes the carbon dioxide emission increase than usual due to unexpected acceleration and deceleration.

In this paper, we proposed an overtaking action control method based on FCFS policy in order to solve the overtaking conflict. It is based on the token-based algorithm and we assigned a part of lane that is right next to the platoon as a critical section. One member of the platoon manages and issues the token so that only one vehicle having the token are able to enter the critical section. Thus, vehicles around the platoon could avoid emitting extra carbon.

The proposed method consists of four phases. In addition, our proposal especially considers about the starving problem and dead lock, avoids those problems. Thus, only one vehicle could enter the critical section in any case and the platoons guaranteeing enough distance between them.

We evaluated our proposal in terms of the CO2 emissions through the computer simulations. The result said our proposal cuts down unnecessary acceleration and deceleration without preventing smooth traffic flow. The proposal kept the average speed of vehicles as fast as normal drivers' action. At the same time, the proposal reduces CO2 emissions, it is 21.24% in terms of the trip time average and 18.73% in terms of the trip distance average.

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