Vehicular Acceleration Advisory Algorithm Using V2V Communication in Highway Junction Point

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Abstract— **The highway junction point, where the ramp is merged with the mainstream, is the main traffic congestion point in the highway when handling transport demands. A vehicle driving on the ramp generally attempts to enter the highway without predicting the traffic condition, and commonly causes traffic congestion on highways. Traffic congestion in the highway junction is defined as the traffic situation that the transport demand in the conjunction point exceeds the bottleneck capacity and the accumulated demand remains to the bottleneck. Under traffic congestion, vehicles driving on the ramp cannot efficiently enter the highway. As a result, the waiting time of the vehicle on the ramp becomes long, and fuel consumption and CO_2 emission increase due to the frequent acceleration and deceleration. In this paper, we propose a vehicular speed acceleration advisory algorithm for the vehicle on the ramp at the junction point. By recognizing the traffic condition on highways using V2V (Vehicle-to-Vehicle) communication, the proposed algorithm helps to reduce the frequent acceleration and deceleration by drivers. From the simulation results, compared to the conventional driving on the ramp, we show that the proposed algorithm can decrease fuel consumption, CO_2 emission under various vehicle densities.**

I. Introduction

According to a US INRIX survey conducted in 2015, 471 urban highways throughout the United States spent more than 3 billion gallons of fuel and over 7 billion hours of traffic due to traffic congestion [1]. This surey showed that traffic congestion on highways cause much fuel consumption and the large waiting time.

To handle traffic congestion on highways, many research and standardization efforts using V2X(Vehicle-to-Everything) networks have done. In the United States and Europe, standardization is in progress under the names of IEEE WAVE and ETSI ITS G5 [2]. V2X networks operates using ad-hoc communication between network terminals such as OBU (On-Board Unit) and RSU (RoadSide Unit). Especially, it is known that V2V (vehicle-to-vehicle) networks showed the good efficiency in eliminating traffic congestion. By exchanging information between vehicles through messages such as BSM (Basic Safety Message) and CAM (Cooperative Awareness Message), V2V can help to improve traffic condition.

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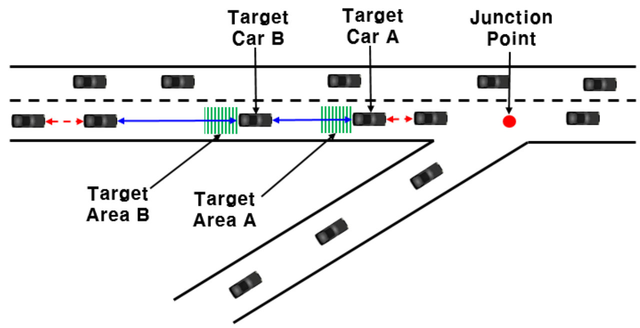

Fig. 1: Traffic congestion example on junction point

As a representative example using a V2X networks, GLOSA (Green Light Optimized Speed Advisory) [3] is designed to advise the OBU of the vehicle by using the V2X communication and obtain traffic light information at intersection from the RSU. GLOSA helps the vehicular to pass the intersection with the low waiting time. Thus, traffic congestion at intersection is elliminated and fuel consumption of the vehicle is decreased.

In this paper, we consider traffic congestion on the highway junction point, where the ramp is merged with the mainstream. We note that one of the major reasons of traffic congestion on highways is the merge of traffic coming from the ramp with traffic on the mainstream. Specifically, traffic congestion on the highway junction point is issued because vehicles driving on the ramp enter the highway without knowing the traffic condition of the mainstream. Since vehicles on the ramp frequently needs to accelerate and decelerate at the conjunction point before entering the mainstream, the waiting time and the fuel consumption of the vehicles on the ramp increase.

To resolve the traffic congestion problem on the highway junction point, we propose a vehicular speed acceleration advisory algorithm. By recognizing the traffic condition on the mainstream using V2V communication, the proposed algorithm can reduce fuel consumption, CO_2 emission under various vehicle densities. As a comparative research work, MinjinBaek et.al. proposed a method for obtaining vehicle speed and position information using V2V communication [4]. In [4], the risk evaluation formula is used to control the speed of vehicles for collision avoidance [4]. Also, Dan Marinescu et. al.'s proposed an algorithm for efficient traffic merge on the highway [5]. Dan Marinescu et. al.'s algorithm

Algorithm 1 Overall operation of Proposed algoritm

```
Require: BSM_Set received BSM, SelfCarInfo
Require: isBreak = False, a_acc, a_dec
  procedure AdvisoryAlgorithm(BSM_Set)
    while isBreak == FALSE do
      isBreak = TRUE;
      ExtractedInfo = InfoExtraction(BSM_Set);
      TC = TC_Selection(ExtractedInfo);
      TA = TA_Selection(TC);
      Class = MurgeJudgment(TA, SelfCarInfo);
      if Class == A then
        isBreak = FALSE;
      else if Class == B then return 0;
      else if Class == C then
        a_acc= AccelCalc(); return a_acc;
      else
        a_dec=DecelCalc(); return a_dec;
      end if
    end while
  end procedure
```

used the so-called slot-based operation using V2I (Vehicle to Infrastructure) communication.

II. Proposed Algorithm

In this section, we explain the operation of the proposed algorithm in detail. In Figure 1, we show a traffic congestion example which the proposed algorithm targets on.

Let us assume that the vehicle is driving on the ramp without knowing the traffic condition of the mainstream of the highway. In this situation, the vehicle on the ramp does not enter the mainstream immediately and waits in the conjunction point, which is called Wait-and-Merge (WaM) operation. The Wait-and-Merge (WaM) operation raises two issues: (1) Energy efficiency is low due to fuel consumption due to frequent acceleration and deceleration while waiting at the conjunction point; and (2) the vehicle starts to drive in a stationary state and it invokes a cascade speed reduction. The proposed algorithm resolves the two issues by advising the speed of the vehicle at the ramp based on the position and speed of vehicles at the mainstream by using V2V communication. Specifically, OBUs on vehicles at the ramp receive BSM from adjacent vehicles using V2V communications. OBU sends BSM to neighbor vehicles every 0.1 second following IEEE WAVE specifications.

We show the pseudo code of the proposed algorithm in Algorithm 1, where $SelfCarInfo$ consists of the speed and current position of the vehicle, and a_{acc} and a_{dec} are the advised acceleration and deceleration speed respectively. By analyzing the BSM set received for one second, the proposed algorithm operates following five steps. First, the algorithm extracts the necessary information for acceleration/decelation calculation from the received BSM Set (Line 4). Second, the algorithm selects the target car and target space on the ramp (Lines 5 and 6). Third, vehicles on TA, which is the space where vehicle on the ramp gets caught, are divided into four classes, i.e., A, B, C and the other, based on the time required to reach the conjunction point. Each class determines the feasibility of merging (Line 7). Finally, according to class that vehicles belongs to, either the efficient acceleration or the efficient decelaration speed is advised for each vehicle (Lines 8 to 15).

TABLE I: Terms and Notation

Terms	Notation
D_j	Distance to junction point
v_{cur}	Current speed
v_{max}, v_{min}	Maximum and minimum limit speed of the highway
a_{max}, a_{min}	Maximum and minimum speed of a vehicle
t_{ts}, t_{te}	Start and end time the vehicle's staying at the target area

To operate as shown in Algorithm 1, the proposed algorithm consists of four functional modules: (1) Information Extraction; (2) TC(Target Car) and TA(Target Area) Selection; (3) Merging Judgement; and (4) Acceleration/Deceleration Calculation. Let us overview each module in details. In Table I, we show terms and notation used in the followings.

1) Information Extraction: Vehicles at the ramp extract the necessary information from the BSM received from the neighbor vehicles. The extracted information is the current speed and position of each vehicle on the highway. This information is used to calculate the time required for each vehicle on the highway while reaching the junction point.

2) TC(Target Car), TA(Target Area) selection: For safety merging, the position information in BSM is used to select a TC which has a distance of 80m or more distant from the rear vehicle on the highway. Next, the position information in BSM is used to select the TA up to 20m behind the TC.

3) Merging Judgment: Whether vehicle on the ramp can get in TA when it arrives at junction point is determined based on three vehicle mobility models. The vehicle mobility model is divided the time taken for the vehicle to travel to the junction point based on the current speed, the maxmin acceleration, and the distance to the junction point [6]. First model keeps constant velocity motion at the current speed. The time to reach the junction point are as follows:

$$t_{cur} = \frac{D_j}{v_{cur}} \tag{1}$$

Second model is used to accelerate vehicles with the maximum acceleration speed. After making the vehicle reach the maximum speed, second model performs the constant-speed motion. The time to reach the junction point using the second mobility model are as follows:

$$t_{min} = \frac{D_j + \frac{(v_{max}-v_{cur})^2}{2a_{max}}}{v_{max}} \tag{2}$$

Third model decelerates vehicles with the maximum deceleration speed. After making the vehicle reach the minimum speed, third model performs the constant-speed motion. The time to reach the junction point using the third mobility model are as follows:

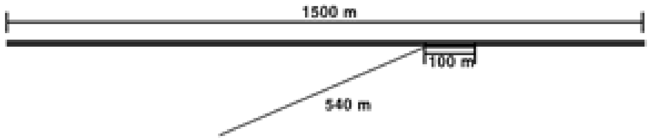

Fig. 2: Abstract of Simulated Highway Environment

$$t_{max} = \frac{D_j + \frac{(v_{cur} - v_{min})^2}{2a_{min}}}{v_{min}} \tag{3}$$

By following each mobility model, vehicles at the ramp are classified into four categories based on the time reaching the junction point as follows:

a) *Class A :* $t_{max} < t_{ts}$ or $t_{te} < t_{min}$
b) *Class B :* $t_{ts} < t_{cur} < t_{te}$
c) *Class C :* $t_{min} < t_{te}$ and $t_{te} < t_{cur}$
d) *Class D :* $t_{cur} < t_{ts}$ and $t_{ts} < t_{max}$

If it is determined as class A, it cannot be merged into TA even if maximum acceleration or deceleration is performed. Otherwise, go back to TC selection and select TA again. In case of class B, vehicle drives constantly at the current speed. Finally, in case of C and D classes, acceleration or deceleration is performed because it is merged into TA while decelerating or accelerating speed.

4) Acceleration / Deceleration Calculation: For vehicles belonging to Class C, acceleration speed is advised, and advisory acceleration speed can be calculated as follows:

$$a_{acc} = \frac{(v_{max} - v_{cur})^2}{2(t_{te}v_{max} - D_j)} \tag{4}$$

For vehicles belonging to Class D, deceleration speed is advised, and recommended deceleration can be calculated as follows:

$$a_{dec} = \frac{(v_{cur} - v_{min})^2}{2(t_{ts}v_{min} - D_j)} \tag{5}$$

III. Evaluation Result

To verify the performance of the proposed algorithm, we measured the CO_2 emission from a simulation. When calculating CO_2 emissions, we used the EMIT model integrated in Veins. EMIT is a simple statistical model for calculating CO_2 emissions and fuel consumption for vehicles based on speed and acceleration. For our experiment, we used the 'Category 9 model [7].

A. Simulation Environment

The simulation tool used in the experiment is as follows. Sumo 0.30v to generate vehicle traffic, Omnet ++ 5.2v to perform communication between vehicles, and Veins 4.6v to perform information exchange between two tools.

As shown in Figure 2, we considered the highway which consists of the mainstream of 1500m and the ramp of 540m, and the merge line of 100m. We considered a total 400 of vehicles, where consists of 300 vehicles on the mainstream and 100 vehicles on the ramp. Also, the start speeds of all vehicles are set randomly.

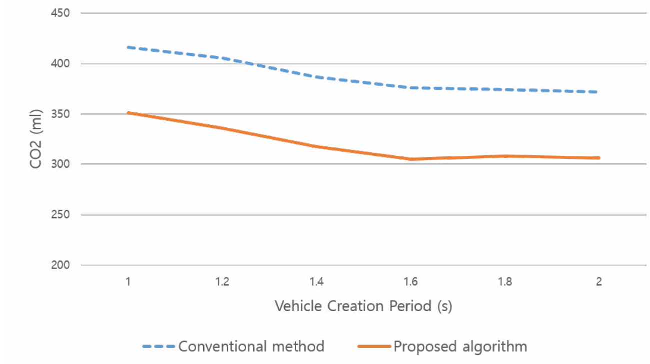

Fig. 3: CO_2 Emission

B. Simulation Results

Every simulation, we changed the vehicle density on the highway by setting the generation period of vehicles on the highway from 1s to 2s. From five times of iterations for every period, we measured the average result. From Figure 3, we can observe that CO_2 emission is decreased under all vehicle density values. Specifically, when the vehicle generation cycle changes 1 to 2, it is observed that the average value of CO_2 emission is decreased by as much as 17.38% in average.

IV. Conclusion

In this paper, we proposed a vehicular speed accelearation advisory algorithm using V2V communication. We showed that by advising the acceleration and deceleration of the vehicle on the ramp, the proposed algorithm decreased CO_2 emission by as much as 17.38% in average. Even though the proposed algorithm is efficient at reducing the frequent accelearation and deceleration, the proposed algorithm is limited to advising the acceleration speed only for vehicles on the ramp, not vehicles on the mainstream of the highway. In the neare future, we are supposed to extend the current work to advise not only vehicles on the ramp but also vehicles on the mainstream on the highway.

Acknowledgment

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