An Alleviating Traffic Congestion Scheme Based on VANET with a Function to Dynamical Change Size of Area for Traffic Information in Urban Transportations

Shinji Inoue, Yousuke Taoda, Yoshiaki Kakuda
Graduate School of Information Sciences
Hiroshima City University
Hiroshima, Japan
{shnj-496@, taoda@nsw.info., kakuda@}hiroshima-cu.ac.jp

Abstract— **The traffic congestion frequently occurs in urban transportations. Network services for alleviating the traffic congestion based on vehicle networks have been studied currently. Vehicle Information and Communication System (VICS) is one of the network services. It has been developed in Japan. However, since each vehicle can obtain global information on traffic congestion using VICS, all vehicles in the congested areas tend to move to non-congested areas. As a result, the non-congested areas become congested areas. To avoid such an oscillation between the congested and non-congested areas, we have proposed an Alleviating Traffic Congestion method (ATC). In the ATC method, each vehicle gathers traffic information in a limited area where the vehicle exists by using a Vehicle Ad hoc Network (VANET). The size of limited area is constant in the original ATC method. However, we consider that the size of the limited area should be adaptive depending on traffic condition. This paper proposes a modified ATC method, which can change the size of the limited area depending traffic condition. Through simulation experiments, this paper shows that the proposed method provides faster velocity and shorter trip time than VICS in the environments that traffic varies temporally and spatially, which occur in urban transportations.**

Keywords-alleviating traffic congestion; vehicle density; average velocity; VANET; simulation

I. INTRODUCTION

In order to alleviate the traffic congestion, the Vehicle Information and Communication System (VICS) [1] is famous in Japan. In VICS, ultrasonic vehicle detectors or other vehicle detectors, which are deployed by traffic control centers, report traffic information at the point where each detector is deployed to VICS center. The VICS center analyzes global traffic information reported by the vehicle detectors and generates traffic congestion information. The traffic congestion information is broadcasted by character multiplex, radio beacons, or optical beacons to vehicles. Vehicles which receive traffic congestion information can select driving routes where the routes do not go through congested areas. However, VICS depends on road-side infrastructure, for example vehicle detectors. If traffic congestion happens in an area where vehicle detectors are not deployed, VICS cannot broadcast the above traffic congestion information. Moreover, a research report [2] says that new traffic congestion would be caused when ratio of the number of vehicles in which a VICS terminal is installed to the number of all vehicles exceeds 50%. It is because vehicles in which a VICS terminal is installed would perform a similar behavior and the vehicles would pass through the same roadway segment.

Vehicle route management systems based on centralized servers have been proposed in [3] [4]. In [5], a distributed traffic navigation system has been proposed but road-side infrastructure should be required for each intersection.

Instead of global information obtained by VICS, this paper utilizes local information obtained by the Vehicle Ad hoc Network (shortly, VANET). There are lots of research results on collection of traffic congestion information using VANET. Shibata et al. [6] proposes a method to divide a transportation network into non-overlapped areas and to detect areas where congestion occurs in the transportation network using VANET. In the proposed method, each vehicle records not only the traffic congestion degree of roads through which the vehicle has passed but also the traffic congestion degree of roads through which the other vehicles have passed by exchanging it with them. As time proceeds, the entire traffic congestion information in the transportation network can be obtained by integrating the recorded information. Shinkawa et al. [7] proposes another method to obtain the entire traffic congestion information in the transportation network using cyclic vehicles such as fixed route buses. Yamashita et al. [8] proposes a method to suggest an appropriate route using the road-to-vehicle communication as follows. First, each vehicle sends route information to reach the destination to a central server located in the roads using the road-to-vehicle communication. Next, the central server, which received the route information from many vehicles, calculates an appropriate route to the destination and sends back the calculated route information using the road-to-vehicle communication. However, to our knowledge, there are no proposals which are based on the traffic congestion information collected by VANET, each vehicle independently decides a route to alleviate traffic congestion in the transportation network.

In [11], we have proposed an Alleviating Traffic Congestion method (shortly, original ATC method.) The original ATC method works on each vehicle. Also the method suggests driving route information to each vehicle based on traffic information in a limited area around the vehicle.

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In the original ATC method, the size of a limited area is constant. However, we consider that the size of a limited area should be changed depending traffic condition. In this paper, we propose a modified Alleviating Traffic Congestion method (shortly, a modified ATC method.)

The rest of this paper is organized as follows. In Section II, we explain transportation engineering. Next, we propose the modified ATC method in Section III. Section IV shows results of simulation experiments. Finally, we conclude our paper in Section V.

II. TRANSPORTAION ENGINEERING

In transportation engineering, a stream of vehicles on a roadway segment is mainly characterized by three kinds of variables. They are traffic volume, density, and velocity. A roadway segment is a part of roadway where there exist neither junctions nor road forks in the part. Traffic volume is the number of vehicles which pass through a fixed measuring point per unit time. Density is defined as the number of vehicles per unit length of roadway. A velocity of each vehicle is individual. So, in order to characterize a stream of vehicles, time average velocity and space average velocity are calculated. Time average velocity is the average of vehicles velocity when each vehicle passes through a fixed measuring point during a fixed period. Space average velocity is the average velocity of the vehicles in a whole roadway segment at a fixed time instance. Both time average velocity and space average velocity would be influenced by traffic signals.

There exist some relations among traffic volume, density, and velocity. First, we mention that a relation between density and velocity. The higher density of vehicles is, the slower velocities of vehicles are. Relations between density and velocity are observed by many researchers and several relation models are proposed. In this paper, we adopt an equation of Greenshields model [9],

$$v = v_f(1-k/k_j) \quad (1)$$

where v is velocity, v_f is a parameter, which is called as free velocity, where a driver chooses velocity under a situation where no traffic flows affect the driver, k is density, and k_j is a parameter which is called as jam density which is the upper bound of density. Next, we mention that a relation between density and traffic volume. If density of vehicles is zero, traffic volume is obviously zero. While density of vehicles is less than some threshold, increasing the density causes increasing traffic volume. However, increasing the density makes velocities of vehicles slower. Consequently, when the density of vehicles is over the threshold, increasing the density causes decreasing traffic volume. At last, it makes velocities of vehicles to be zero because density of vehicles becomes saturated. Then traffic volume becomes zero. The threshold is called as critical density.

III. MODIFIED ATC METHOD

In this section, we describe the modified ATC methods.

A. *Assumptions*

In this paper, we assume the following matters on each vehicle.

- Each vehicle has a wireless communication function in order that such vehicles can form a VANET.
- Each vehicle has a GPS or a function showing an ID of roadway segment in which the vehicle currently exists.
- Each vehicle has road map information in order to show a receiving side vehicle's position to a road map.

Also, we assume the following matter on each roadway segment.

- Each roadway segment is not a one-way street, that is, each roadway segment is bi-directional way.

B. *Outline of the Original ATC Method*

In the original ATC method [11], since traffic congestion varies as time advances, each vehicle independently performs the following actions.

- Action 1: Each vehicle periodically broadcasts a request message through a VANET to obtain information of vehicles in the limited area around the vehicle.

For convenience, we call a vehicle which broadcasts the message a sending side vehicle. Also we call a vehicle which receives the message a receiving side vehicle.

All request messages have a same Time-To-Live (shortly, TTL) value. If TTL value of the request messages is equal to N, the request messages are re-broadcasted N times by receiving side vehicles.

- Action 2: Each receiving side vehicle replies a response which includes information about the vehicle (vehicle ID, velocity of the vehicle, roadway segment ID in which the vehicle exists, etc.)
- Action 3: The sending side vehicle receives responses from the receiving side vehicles and evaluates each roadway segments based on the responses.

To evaluate a roadway segment is estimating trip time where a vehicle goes through the roadway segment. In Action 3, each vehicle receives responses. Therefore, each vehicle knows density of vehicles in roadway segments. Following relations between density and velocity are well known. The higher density of vehicles is, the slower velocities of vehicles are. That is, each vehicle estimates velocity of vehicles in a roadway segment by density of vehicles in the roadway segment.

- Action 4: The sending side vehicle calculates a route for a destination of the sending side vehicle.

By the estimating trip time of roadway segments, each vehicle finds time-shortest path to a destination of the vehicle. A situation of each roadway (congested, non-congested) is varying as time goes by. In order to adjust current roadways' situations in real time, the above instructions are performed repeatedly.

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C. The Modified ATC Method

Basic ideas of the original ATC method are as follows. First, the original ATC method leads vehicles to go through in time-shortest path. Next there might exist many roadway segment whose density of vehicles are small in the time-shortest path. As a result, vehicles which are in congested area would go to non-congested area.

However, suppose that the TTL value of request messages is small. In heavy vehicle traffic, the original ATC method could not find roadway segments whose density of vehicles is small. Also, it becomes fail to lead vehicles from congested areas to non-congested areas.

Conversely, suppose that the TTL value of request messages is large. Even in heavy traffic, the original ATC method might find roadway segments whose density of vehicles is small. However, the larger the TTL value is, the more vehicles know the low density roadway segments. Therefore, a large number of vehicles tend to gather in the low density roadway segments. As a result, a new traffic congestion would happen in the low density roadway segments.

We consider that the TTL value of request packets is adaptive to traffic conditions. A basic policy of the modified ATC method is to control the TTL value where the number of non-congested roadway segments which each vehicle can find is some fixed range (for example, the number of non-congested roadway segments is more than beta and less than gamma.)

Here, we describe the modified ATC method. The modified ATC method is same as the original ATC method except the followings.

After Action 3 of the original ATC method, the modified ATC method performs an adjusting TTL value operation.

Adjusting TTL value operation:

(1) Select responses which are sent from receiving vehicles in a half circle facing to a destination as depicted in Fig. 1. There exists Car X in the center of a circle. A destination of Car X is the corner of top right. In this case, the adjusting TTL value operation selects responses form a half circle of A.

(2) Count the number of non-congested roadway segments. (A density of vehicles parameter alpha is given. When density of vehicles of a roadway segment is less than alpha, the modified ATC method recognizes that the roadway segment is non-congested.)

(3) Suppose that the number is equal to K. If K is less than beta, increment TTL value by one. If K is greater than gamma, decrement TTL value by one. (Parameters beta and gamma are given. Beta is less than gamma. In order to avoid that TTL value becomes too large or too small, an upper bound and an lower bound of TTL value are set.)

IV. EVALUATIONS

In order to evaluate influence of parameters beta and gamma in the modified ATC method, we performed simulation experiments. For evaluating influence parameters,

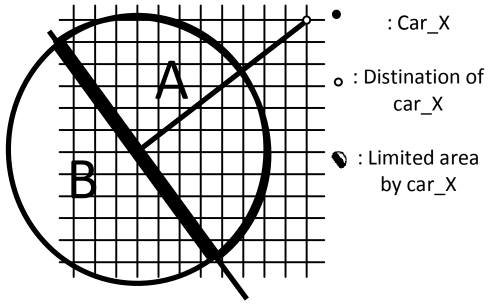

Figure 1. Area for selecting responses

we performed the following combinations of beta and gamma, (15, 25), (20, 30), (40, 50), (25, 40), (10, 30), (30, 50), (20, 50). (The first element means beta. The second element means gamma.)

In this simulation experiments, we adopt that congestion threshold density alpha is equal to 60 vehicles per a kilometer.

We performed one simulation experiments for each combination.

A. Simulation Environments

There exist no traffic flow simulators supporting inter-vehicle communications to our knowledge. So, we have developed a traffic flow simulator supporting inter-vehicle communications.

(1) Inter-Vehicle Communications

In the simulator, any two vehicles can communicate at any time in a single-hop communication if a distance between the two vehicles is less than a wireless communication range which is a given parameter. Moreover, the simulator does not take into consideration the communication delay time. In our simulation experiments, we set a wireless communication range 250 m.

(2) Setting Roadway Parameters

We have performed simulation experiments under the following road parameters. (See Table I)

(3) Setting Vehicle Parameters

(3-a) Control of Acceleration and Deceleration

The simulator prepares a function where each vehicle accelerates or decelerates based on a traffic flow model which is called as "Optimal velocity model" [10]. In this model, an optimal velocity is determined by a non-linear monotonic function of headway distance.

TABLE I. PARAMETERS ON ROADWAY SEGMENTS

Road network pattern	Square grid
Size	12 grid x 12 grid
Size of each grid	500 m x 500 m
Traffic signals	One for every intersection
Time period for red signal	67 s
Time period for yellow signal	3 s
Time period for green signal	60 s

TABLE II. TOTAL NUMBER OF THAT EACH ROADWAY SEGMENT BECOMES CONGESTED

beta, gamma	Total number of congestions
15, 25	24984
20, 30	22608
40, 50	19979
25, 40	20083
10, 30	19132
30, 50	18895
20, 50	16034

(3-b) Scenario of New Vehicles' Appearances

In these simulations, we prepared the same scenario where congested areas and non-congested areas appear and these areas relocate as time progresses. We omit the details of the scenario because of a page limit.

B. Results

Table II shows the results on total number of that each roadway segment becomes congested.

C. Considerations

The simulation results show that the number of congestion becomes small when the difference of beta and gamma is large. In the simulation of combination (15, 25), we consider that low value of gamma forces that TTL value becomes too small. In this case, changing operation of TTL value is influenced from value of gamma rather than traffic conditions.

Conversely, in the simulation of combination (40, 50), we consider that high value of beta forces that TTL value becomes large.

V. CONCLUSION AND FUTURE WORK

This paper has proposed the modified ATC method. In the modified ATC method, size of area for gathering traffic information is changeable depending on traffic conditions. For changing size of area, the modified ATC method introduces two parameters. Simulation results show that various combinations of parameters make a different influence for alleviating traffic congestions. In future work, we would like to analyze influences of parameter combinations for alleviating traffic congestion.

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