Research on Traffic Signal Self-Organizing Control Based on VANET Acquisition Information

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Abstract: In order to solve the phenomenon of traffic congestion and severe oversaturation overflow in urban road network, this paper proposes a self-organized traffic signal control method which based on vehicular ad-hoc network to collect information and aim at evacuating network oversaturated congestion traffic. At the same time, the method is based on fuzzy control theory and take containable traffic space in the front road section into consideration. Then the road network oversaturation intersection signal control models are established. Furthermore, based on the secondary development of VISSIM, the simulation experiment and evaluation of fixed signal timing, fuzzy signal control and traffic signal self-organizing control based on VANET are carried out respectively. The results show that the method proposed in this paper has the obvious effect on traffic congestion evacuation and the improvement of road network capacity.

1. Introduction

In recent years, with the rapid development of information technology and various modern theories, traffic signal control system based on vehicle-to-vehicle technology, intelligent control technology and self-organizing control technology has become a hot research direction in intelligent transportation field [1]. With the expansion of the city scale, congestion and frequent accidents, the traffic signal control system needs to respond more quickly to the real-time traffic changes of the road network. However, the existing urban traffic signal control system mostly adopts centralized control mode which has many deficiencies in the real-time performance and accuracy of its data, and the adaptability to the dynamic changes of traffic conditions. Especially when the road network oversaturation phenomenon occurs, the residual queue and overflow occur frequently in the intersection [2], which may lead to a large deviation in the traffic data. Taking into account the accuracy and timeliness of VANET information collection, therefore, combined with VANET data acquisition, this paper will explore a traffic signal self-organizing control system of urban road network based on fuzzy signal control and over-saturation network self-organizing signal control, which is used to evacuate traffic jam.

2. Vehicular Ad-hoc Network

In order to avoid the queuing vehicles at the downstream intersection overflow to the upstream intersection, accurately calculating the queue length and taking effective control strategies are vital to control the traffic status of the road network. Geared to the needs of urban road network, this paper is based on real-time vehicle information, such as vehicle location, speed and vehicle distance, which are obtained through vehicular ad-hoc network, and fully considers the information interaction and relay transmission in the process of vehicle driving [3], then builds model of vehicle information acquisition

based on VANET and queue length model, which provide real-time and accurate dynamic traffic data source for signal timing. The brief model is as follows [4]:

$$\left\{V_{i,k}(t), L_{i,k}(t) \mid i = 1, 2, \ldots, N, k \in V(i)\right\} \tag{1}$$

In the formula, $V_{i,k}(t)$, and $L_{i,k}(t)$ respectively represent the travel speed of the vehicle k on the road i and the distance traveled by the vehicle k into the road segment i at time t. N is the total number of road sections in the road network, and V(i) is the vehicle set on section i.

When $V_{i,k}(t)$ is less than congestion speed determination threshold(Qv), the vehicles on the road segment i are in a congested state, and the vehicle queue length of the road segment i is:

$$L_i(t) = L_i - \left\{\min L_{i,k}(t) \mid V_{i,k}(t) < Q_v, k \in V(i)\right\} \tag{2}$$

Here, $L_i(t)$ represents the queue length of the congested vehicle on the road i at time t, L_i represents the length of the road i,and Q_v is the congestion speed determination threshold (usually set to 5 km/h).

3. Fuzzy Controller Design

Fuzzy control, as a rule-based intelligent control method, has good real-time online control effect for urban traffic signal control system with large randomness and difficult to establish accurate mathematical model [5]. The basic idea is that when the traffic flow of a certain phase at the intersection is less, the green time of the phase should be reduced as soon as possible, and when the traffic flow is large, the green time of the phase should be extended. The purpose is to avoid the waste of green time, and to minimize the average delay of vehicles passing through the intersection, and to increase the total traffic volume of the intersection. The control process of the multi-phase fuzzy controller in urban traffic signal system [6] is described as follows: traffic information collection is carried out by vehicle ad-hoc network, the queuing length of the current phase and the queuing length of the next phase are set as the input variables of the fuzzy controller. Then, through the process of the fuzzification, fuzzy reasoning and clarification of the steps, we can get the output variable value of the fuzzy control, that is, the current phase green light extension time. Thereby the self-organized signal control of the traffic flow is realized.

4. Self-Organizing Signal Control Method for Oversaturated Road Network

4.1 Oversaturated Junction

(1) oversaturated road section: it refers to that the queue length of congested traffic flow on road section is larger than the oversaturation queue threshold QL.

(2) oversaturated road junction: if there is a oversaturation phenomenon in a section of the road network, the two junctions adjacent to the road section are called oversaturated road junctions. They are divided into the the edge intersection of the oversaturated road network and the middle intersection.

(3) oversaturated road network edge intersection: the edge intersection of a congested area consisting of multiple adjacent oversaturated sections in a road network is called oversaturated road network edge intersection. According to the outflow direction or inflow direction of the oversaturated traffic flow, it can be divided into oversaturated road network outflow edge intersection and oversaturated road network inflow edge intersection.

(4) oversaturated road network middle intersection: the inner junctions of congested area composed of multiple adjacent oversaturated roads are called oversaturated road network middle intersection. The inflow and outflow sections of the intersection are oversaturated sections.

4.2 Control Principles and Strategies

For different oversaturated junctions, the relevant phase timing control will be performed according to the following criteria. That is:

The general principle of self-organizing signal control for oversaturated road network is to dissipate the congestion traffic flow of the oversaturated road network, and to consider the traffic

space that can be accommodated in the front section(whether it is oversaturated). Specific content is divided into the following:

(1) Evacuating the congested traffic flow as soon as possible so as to make the length of the oversaturated traffic flow reduced to a certain distance from the end of the road, that is, the state of intersection is changed from oversaturated to non-saturated.

(2) When adjusting the signal phase of a oversaturated junction, the traffic condition of the adjacent intersection should be taken into account, so as to prevent the occurrence of the congestion or more serious congestion at the adjacent intersection.

(3) Transferring the oversaturated traffic flow to the non-saturated intersection, and the queue length threshold is used to ensure that the non-saturated intersection will not occur queue overflow phenomenon.

Thus, the self-organizing coordination control strategies of oversaturated road network is formed.

4.3 Control Models

According to the traffic data acquired by VANET, the current status of the intersection and each road section (whether it is oversaturated) is judged according to the vehicle queue length. When the oversaturated state occurs in the road network, the corresponding signal control models are established for different intersection and section status. The oversaturated junctions described in this paper are divided into three types: the outflow edge intersection of the oversaturated road network, the inflow intersection of the oversaturated road network, and the middle intersection of the oversaturated road network. Concrete example is shown in Figure 1.
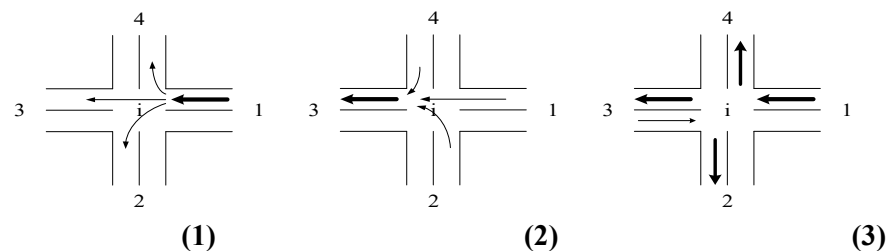

(1)   **(2)**   **(3)**
Fig.1 Schematic diagram of three kinds of supersaturated road network

Here: 1, 2, 3, 4 are the four intersections adjacent to intersection i, the thick solid line is the oversaturated road section adjacent to intersection i. For the convenience of research, we set $G_{i,j}(t)$ as the traffic flow state on the road section which connect the intersection i to the intersection j at time t. $G_{i,j}(t)=1$ is the state of oversaturated traffic, $G_{i,j}(t)=0$ is the state of unsaturated traffic. And $G_{i,j}$ represents the road section which connect the intersection i to the intersection j.

In this paper, the signal phase adopts four-phase system and fixed phase sequence, namely east-west direction straight, east-west direction left, south-north direction straight and south-north direction left.

(1) The signal control model of oversaturated road network outflow edge intersection (refer to figure 1(1))

1) The first phase and the second phase

This paper takes the first phase (east-west direction straight) as an example to illustrate, and the second phase (east-west direction left) is similar.

If the green signal of the current oversaturated section is the first phase, in order to evacuate the over-saturated traffic flow of this section as soon as possible and on the basis of considering the containable traffic space of the front section of traffic flow evacuation, the green time of the first phase and the second phase should be increased as much as possible. In all the models in this paper, the right turn flow is not controlled by signal. The signal control model is as follows:

Set t as the current moment, t_1 is the time when the signal of the oversaturated link($G_{1,i}(t)=1$) is converted to the first phase, at this time its green light timing $T_{1,i}(t_1)$ is:

$$Tmin \leqq T1,i\,(t1) \leqq Tmin + \Delta t\,(\leqq Tmax\,) \qquad\qquad （3）$$

Here, Tmin and Tmax are the shortest and the longest phase green light time respectively, Δt is the green time of the current phase extension, the first phase automatically switches to the next phase when the green time is extended to one of the following four cases (the time at which the second phase is transferred is t2):

① When the phase green light exceeds the maximum green time. At this time, the duration of the first phase green light is: $T1,i(t1) = t2 - t1 = Tmax$.

② The over-saturated section is changed from the oversaturated state to the unsaturated state. When $t \geq ta$, $G1,i(t) = 0$, then the time to the second phase is: $t2 = ta$, the first phase green light duration is : $T1,i(t1) = ta - t1$.

③ The road section ahead appears to be oversaturated within the shortest green light time, at this time the signal continues to perform the shortest green light time. That is when $t = tb$, $Gi,3(tb)=1(t1 \leqq tb \leqq t1+Tmin)$, the first phase green light duration is: $T1,i(t1) = t2 - t1 = Tmin$.

④ During the green light time after the shortest green light time, the road ahead appears to be oversaturated state. That is when $t=tb$, $Gi,3(tb)=1(t1+Tmin \leqq tb \leqq t1+Tmax)$, at this time, the first phase is switched to the second phase $(t2 = tb)$, and the duration of the first phase green light is: $T1,i(t1) = tb - t1$.

2) The third phase(south-north direction straight) and the fourth phase(south-north direction left)

When the signal timing of the oversaturated road section $(G1,i(t)=1)$ enters the third and fourth phase (the entry time is t3, t4), because at this time the red light makes oversaturated congested traffic waiting in line after the stop line, so if the cross direction of the road is not saturated, it needs to end the green time of cross direction as soon as possible and make the phase switch to the oversaturated road outflow direction, namely $T2,i(t3)=T2,i(t4)=Tmin$. When there is a oversaturated traffic flow in the cross direction, it can be processed according to the signal timing method of the oversaturated road section in the first and second phase and the type of oversaturated junction.

(2) The signal control model of oversaturated road network inflow edge intersection (refer to figure 1(2))

If the signal phase is the inflow direction phase (i.e., the first phase and the fourth phase), at this time, the road section of straight ahead is oversaturated, that is, $Gi,3(t)=1$, although the queuing vehicle on road section G1,i has obtained the green light right, but still can not enter the road section Gi,3, at this time the control strategy is the use of fuzzy control, mainly considering the traffic status of the road section G3,i and its forward section Gi,1. When the signal of the intersection i is entered into cross direction phase (i.e., the second phase and the third phase), due to the current phase of release of vehicle does not flow into the over-saturated section Gi,3, the phase of the signal timing is mainly concerned with the traffic condition of the ahead road which the vehicle is about to drive into. The signal control model is similar to the previous one.

(3) The signal control model of oversaturated road network middle intersection (refer to figure 1(3))

For the $G1,i(t)=1$ case, that is, the road segments G1,i is in a over-saturated condition. When at least one of the outflow direction sections of the intersection is over-saturated section, that is, $Gi,j(t)=1$ $(j=2$ or 3 or $4)$, then the intersection is a oversaturated middle intersection.

At this time, the signal timing control mainly takes into account the state of the signal timing road section of the current phase, the state of the front road section of the current phase traffic flow travel, and the state of the adjacent opposite road sections. The analytical method is similar to that before.

5. Simulation and Evaluation

5.1 Simulation Environment Settings

In order to verify the rationality and validity of the proposed method, we carry out the corresponding simulation and evaluation by using Vissim and Visual Studio. The specific simulation settings are as follows:

Simulation road network: as shown in Figure 2, eight vehicles entrances and four intersections, the roads between intersections are two-way four-lane (with left turn lane), the other road sections are two-way six-lanes; Speed limit: 60km/h; At each cross intersection, 50% of vehicles go straight and 25% of vehicles go left and 25% of vehicles go right. Simulation time: 600s-2400s.Vehicle inputs: case 1:3000veh/h (fixed traffic situation); case 2: as shown in Table 1, variable traffic situation.
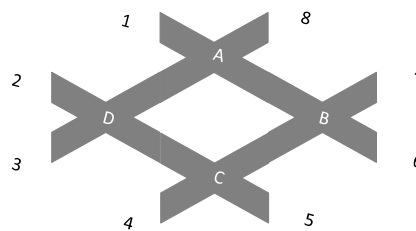

Figure 2 Schematic diagram of the simulation road network

Table 1 Vehicle inputs setting(case 2)

Simulation time(min)	0-10	10-15	15-20	20-25	25-30	30-35	35-40
Vehicle input(veh/h)	3000	3000	1500	500	1500	2000	2000

5.2 Simulation Results and Analysis

In the case of two kinds of vehicle input, this paper carries out simulation of the signal fixed timing scheme, the fuzzy control timing scheme and the self-organizing control timing scheme based on VANET acquisition information, and the comprehensive analysis and evaluation are carried out from the traffic capacity, the average queue length of the intersection, the average delay time of vehicle and the evacuation effect of the congested traffic. In order to facilitate the representation of the graph, we define that fixed represents fixed signal timing, fuzzy represents fuzzy control timing, and self-organized represents the self-organizing control timing.

1) Traffic capacity (See Figure 3 (1))

From the simulation results, it is shown that the total numbers of vehicles cross intersections in 30 minutes with the fuzzy control timing and the self-organization control timing is greatly improved under the two kinds of vehicle input situation.

2) Average vehicle queue length of each road(See Figure 3 (2))

From the simulation results, it is shown that the average queue length of self-organizing control timing is less than that of fuzzy control timing and fixed signal timing in the case of two kinds of vehicle input situation.

3) Average delay time of each vehicle(See Figure 3 (3))

The simulation results show that the average delay time of the self-organizing control timing and fuzzy control timing is reduced compared with fixed signal timing. And the self-organization control timing strategy mentioned in this paper is better.
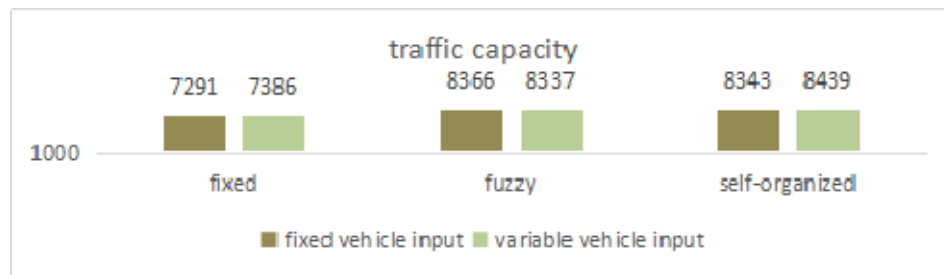
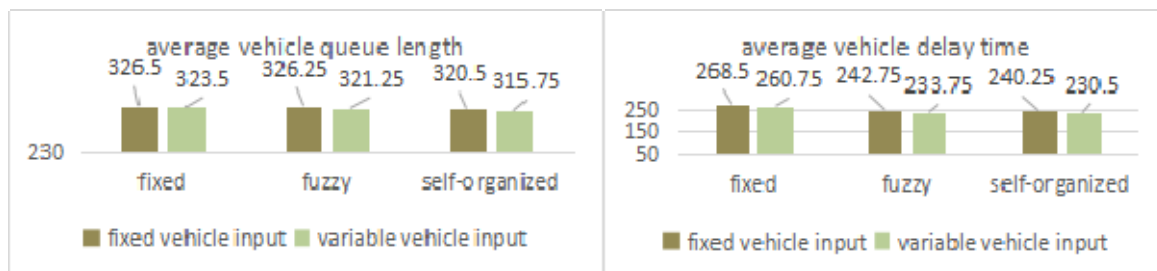Fig.3(1) traffic capacity (veh)

Fig.3(2)   the average queue length(m)   Fig.3(3)   the average vehicle delay time(s)

4) Evaluation of evacuation effect of congested traffic

In two kinds of different network vehicle input situation, local road intersection was oversaturated. Using fixed signal timing at this time will cause a certain import queue overflow to the upstream intersection, which lead to the consequence that vehicles of the upstream intersection can not flow into the downstream intersection but have been waiting in line. This will result in the phenomenon of green light empty [7] and reduce the overall efficiency of the road network. In order to verify the evacuation effect of the proposed method on the congestion flow in the oversaturated state, this paper compares and analyzes the above three kinds of signal timing strategies from the aspects of the congestion time of the road network and the average congestion length of the oversaturated road section. The simulation results are shown in Figure 4 (1) and (2):
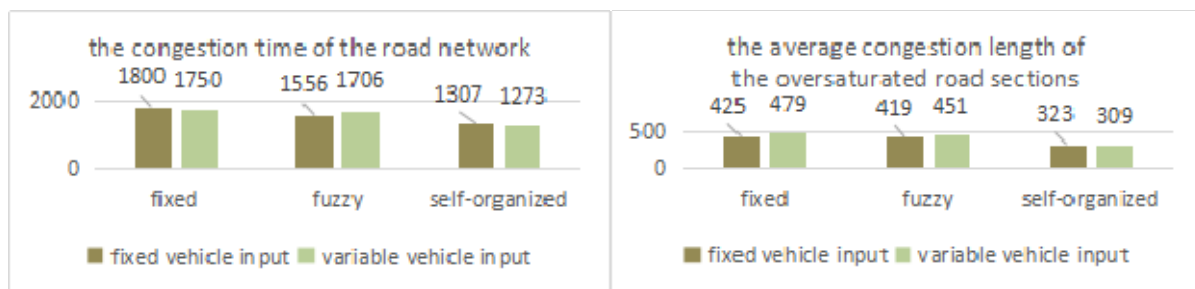

Fig.4(1) network congestion time (s)   Fig.4(2) average congestion length (m)

It can be seen from Fig 4(1) and (2) that under the condition of oversaturation, the self-organizing control timing has significant effects on reducing the network congestion duration and the average congestion length of the over-saturated road network compared with fixed signal timing and fuzzy control timing. Especially in the case of dynamic vehicle input of road network, the control effect of the method proposed in this paper is more prominent, which is about 25-35% higher than that of fixed timing and fuzzy control timing.

Overall, the control effect of the self-organizing traffic signal control method proposed in this paper is superior to the fixed signal timing and fuzzy control timing for the traditional traffic signal control evaluation index. From the point of view of rapid and effective evacuation of traffic congestion,

its congestion evacuation effect is obviously superior to the fixed signal timing and fuzzy control timing.

6. Conclusion

In order to solve the problem of severe congestion caused by commuting peak and traffic accident, this paper puts forward a kind of traffic signal self-organizing control method based on VANET acquisition information, which is based on the fuzzy control theory and meet with the aim of eliminating and diffusing congestion area. This method not only can deal with and solve the problem of signal control under non-saturated traffic condition, but also has the ability of evacuating the over-saturated traffic flow and balancing the traffic flow of road network, which can provide a fast and effective, real-time and accurate self-organizing signal control method with reference value for the realization of large-scale urban road network traffic signal control.

Acknowledgment

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