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V2I Based Intersection Scheduling Algorithm

Dan Shao[1,*1],Jianan Wu[1] and Chao Fu[2]

1 College of Computer Science and Technology, Changchun University, Changchun 130022, China
2 College of Computer Science and Technology, Jilin University, Changchun 130000, China
E-mail: sdsister@163.com

Abstract

Sharp acceleration/deceleration at intersection increases fuel consumption of vehicles, and keeping smooth velocity can save time and oil for drivers. In this paper, we proposed a novel scheduling model based on vehicular ad-hoc networks and autonomous driving system, including vehicle motion, traffic light control and others. Vehicles communicate proactively with traffic lights when approaching to intersections and then transmit required information for scheduling. After summarizing all information about vehicles on different directions, traffic light makes a scheduling decision and distributes a time-slice to vehicle applicants. Simulations show that the proposed model is better than the traditional model in saving time, reducing fuel consumption and improving traffic efficiency.

***Keywords**: Vehicle ad hoc network, autonomous driving, intelligent traffic lights, scheduling model*

1. Introduction

With the surge in car ownership, traffic congestion is becoming serious, the low efficiency of the traffic seriously restricted the development of urban transportation, and the fuel consumed while the vehicle is in motion and the exhaust emitted by the vehicle increased the burden of resources and environment. Therefore, it is urgently needed to have a new scheduling way, on one hand, how to improve the traffic efficiency, on the other hand, how to save energy and reduce emissions. Technology emergence and rapid development of Vehicular Ad-hoc Networks, (VANETs) make the real-time communication of car –car / car - road facilities possible, the driver can get over-the-horizon traffic information [1], which has greatly changed today's driving experience, and laid a solid technical foundation to design a new scheduling method at the intersection.

The car travels at constant speed are usually more fuel-efficient, less emissions [2]. In the traditional scheduling model at the intersection, the vehicle adjusts its running state according to the change in the traffic lights, constantly puts on the brake and starts up, which virtually increased fuel consumption and exhaust emissions. Traditional traffic lights are in the periodic change, and the periodic setting of the red and green lights often relies on the historical statistics and experience. The unreasonable setting of the periodic change often leads to traffic congestion or "starvation" phenomenon, which seriously reduces the traffic efficiency. Traditional traffic lights has an “aggregation effect” on the vehicle, a very loose distribution of vehicles gathers together because of the red light, which also increases the probability of traffic congestion.

In this paper, in the scheduling model of vehicle active intersection, the intersection is considered as the "entity resource", the vehicles are considered as the "users". According to the mode of "application-occupation-liberation", the entity resources are allocated to users

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*Corresponding Author

according to a certain scheduling algorithm, and each user can use the resources fairly and quickly. This mode has fundamentally changed the master- slave relationship between the vehicles and traffic lights, the vehicles do no longer blindly follow the traffic lights, but the initiatively inform the traffic lights of their own existence. After receiving the information, the traffic lights divide time slot for the vehicles to drive, and reasonably allocate resources, so as to ensure the vehicles to cross the intersection smoothly and fast.

2. Related Work

2.1. Automatic Driving

Automatic driving of vehicle is one of the hot topics in modern science and technology. A shadow detection algorithm based on image analysis was proposed in Literature [3], the algorithm combines the pixel detection method and the spatial context to solve the technical problems of distinguishing the object ahead from its shadow (especially the black object and its shadow) in the driving process. Literature [4] detected the effect of moving objects ahead of the vehicle (such as vehicles and pedestrians) on the vehicle by measuring data diffusion method, which has good effect at low speed. A detection and tracking model under the high-speed moving condition was introduced in Literature [5], so that the vehicle can perceive the surrounding conditions in the driving process. Literature [6] proposed a real-time motion planning algorithm based on Fast extended random tree, which can adapt to the complexities of nonlinear, unstable urban environment, and satisfy the security requirements at the same time. Literature [7] constructed a complete and practical automatic driving system, which included environmental awareness, location, path planning and control. The automatic driving vehicles equipped with the system have been driving a hundred kilometers in the actual environment of safely, achieving good results. Literature [8] established a cooperative driving relationship among the vehicles, the vehicle will current vehicle automatically adjust when the vehicle changes the speed, to maintain stable vehicle distance, and avoid the accidents caused by emergency brake.

Automatic driving is the development trend of vehicle control, although it is still facing some technical and legal problems, it can be predicted that the automatic driving will gradually become the development mainstream of intelligent vehicles. Combined with the technology of automatic driving and vehicular ad hoc network, the vehicle and roadside facilities constitute a unified whole, and each vehicle drives based on the planned route and speed, which provides the technical basis for more accurate scheduling. The model in this paper assumes the vehicle and traffic lights can freely exchange information, and the traffic lights can control the time of the vehicle’s arriving at the intersection by adjusting the speed of the vehicle.

2.2.Intelligent Traffic Lights

A method was put forward Literature [9] in which the monitor the traffic flow in all directions at the intersection is detected by the image recognition technology, and then traffic light time step is adjusted according to the size of the traffic flow. Wireless sensor network is used to conduct real-time monitoring in Literature [10] on the length of the vehicles waiting at the intersection in all directions; the intersection with the longest waiting length has the highest priority value, is given priority at the next traffic light transform. Literature [11] adjusted the green sequence of traffic lights and duration of green light through the traffic flow, waiting time and the density of vehicles collected by wireless sensor network and the analysis of these data. The above method has something in common is that the traffic lights collect traffic information, and schedule the traffic according to these information. This method deployment is of a higher cost and can only collect limited information, only considers the traffic efficiency at the intersection while ignoring the driving demand of the vehicle (time saving and energy saving), which is a typical scheduling method centered on the traffic lights. Literature [12] put forward vehicles can adjust their own speed according to the state of the traffic lights, arrives at the intersection in the most reasonable time, avoiding halting time and suddenly speeding up /slowing down, so as to achieve the purpose of saving energy. Although this method takes the vehicle's demand for energy into account, it is a one-way communication between vehicles and traffic lights, and the vehicle can only passively adjust the speed according to the state of traffic lights. Literature [13] proposed a cooperative traffic light scheduling algorithm through utilizing distributed constraint optimization.

In the model of this paper, when the vehicle is close to the traffic lights, a communication link will be initiatively built, to report the information such as speed, direction, so that the traffic lights can get more accurate complete information of the vehicle. It is relatively difficult by using the sensor to predict the driving direction of the vehicle when going through the intersection (turning or going straight), on the contrary, it is relatively easy for the vehicle to voluntarily report this information to the traffic lights. At the same time, with the aid of vehicular ad-hoc network technology, the fixed traffic lights and the vehicle in movement can establish real-time two-way communication, to ensure the real-time scheduling. Combined the technology of vehicle ad-hoc network and automatic driving, traffic lights can directly issue the instruction on the vehicle, maximally keeping smooth speed, and reducing waiting time, and thereby, optimizing the operation effect.

3. Model of the System

3.1.Control Model of the Vehicle

The vehicle establishes a communication connection with the traffic lights ahead in the course of driving through the vehicle communication technology (such as 802.11p), and submits the parameters needed in the scheduling about the distance between the vehicle at the time being and the traffic lights, the speed, the maximum allowable speed and the direction of the vehicle passing through the intersection (going straight or turning). The traffic light scheduling model returns a time t (for example, 20 seconds) to the vehicle after the vehicle submits the information, indicating how long it will be for the vehicle to arrive at the intersection. Vehicles adjust the speed of the in accordance with the amount of time t returned by the traffic lights, and go through the intersection in the time t, the detailed process is shown in Figure 1.

a) at the initial time, the intersection is idle；

b) at the time of t0， Vehicle 2 comes to the intersection, and establishes communications with the traffic lights, submits the distance, speed and other information; Traffic lights inform Vehicle 2 to arrive at the intersection at time of t1 after making a scheduling decision;

c）then at the time of t1, Vehicle 2 arrives at the intersection, the driving direction of Vehicle 2 switches to the green light, at this time, Vehicle 4 comes to the intersection, the traffic lights schedules Vehicle 4 car, informing it should arrive at the intersection at the time of t2;

d）at the time of t2, Vehicle 2 departs from the intersection, the driving direction of Vehicle 4 switches to the green light；

e）Vehicle 4 departs from the intersection，a new vehicle arrives, and then the scheduling continues.

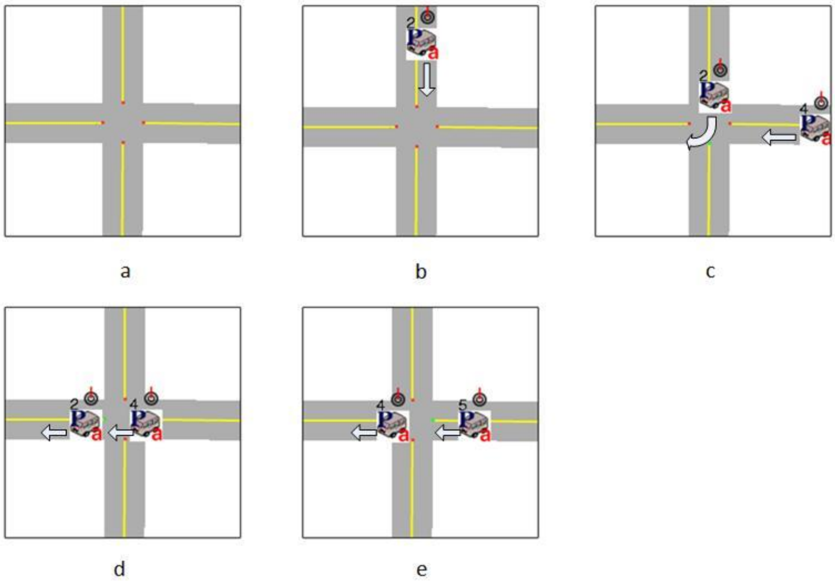

Figure 1. Diagram of Scheduling Process （Arrows Indicating the Direction of Vehicle）

Assuming the distance between Vehicle X and the zebra crossing at the intersection at the time of t0 is sx(t0)， the speed is vx(t0), at the time of t0, Vehicle X sends application to the traffic lights, at the time of t1, the time returned by the traffic lights to Vehicle X is Δt ， then the driving speed of the vehicle satisfies the following constraints after the time of t1:

$$s_x(t_1) = s_x(t_0)\text{-}v_x(t_0)*(t_1\text{-}t_0) \quad (1)$$

$$s_x(t_1) = (v_x(t_0)*\Delta t_1 + \frac{1}{2}*a*\Delta {t_1}^2) + (v_x(t_0) + a*\Delta t_1)*\Delta t_2 \quad (2)$$

$$\Delta t_1 + \Delta t_2 = \Delta t\text{-}t_1 + t_0 \quad (3)$$

$$v_x(t_0) + a*\Delta t_1 \leq vmax_x \quad (4)$$

Wherein, sx(t1)indicates the distance between Vehicle X and zebra crossing at the time of t1, Δt1and Δt2 respectively indicates the time of speeding up and uniform driving of Vehicle X, vmaxx indicates the maximum speed of Vehicle X. To save time and fuel, the adjusted speed vx(t0) + a*Δt1should be closer to vmaxx.

If because of certain circumstances (such as traffic is too heavy), the scheduling cannot be reasonably conducted, the time of t=0 returned by the traffic lights indicates the scheduling fails, the vehicle is not affected by the scheduling, it will come to the intersection and wait for passing in the traditional way.

3.2. Scheduling Model of Traffic Lights

As a resource, the intersection is allocated to the vehicle in the form of time slot; each vehicle will receive the time slot assigned by the system before arriving at the intersection, indicating the timing in which it can pass through the intersection. Time slot may overlap in different vehicles, because the intersection allows more vehicles to go through at the same time (depending on the driving direction of the vehicle and vehicle number).

The scheduling model of traffic lights maintains a motorcade queue, and each vehicle which submits the driving application is added to the queue; the queue satisfies the principle of (FIFO) First in First Out, namely, which is processed according to the time sequence submitted by the vehicle t, and the scheduled vehicle is removed from the queue. At the same time, the scheduling model of traffic lights also maintains a list of time slot, and records the distribution of the current intersection, including the driving direction and driving length. Traffic lights adjust the status of the current light (1s) according to the time slot list. The overdue time slot is removed and the new time slot is added.

The time slot list can be implemented in a one-dimensional array, the value of the array indicates the state of the traffic lights. Taking the simplest intersection of east-west- south-north, as an example, the traffic lights only have three kinds of states: -1 indicates the intersection is idle; 0 indicates the east-west direction is green light and the south-north direction is red light; 1 indicates that the south-north direction is green light and the east-west direction is red light. When the red light is on, the driving is prohibited; the traffic light is on; the driving is permissible (including going straight, left turn and right turn). The maintenance process of the time slot list is shown in Figure 2:

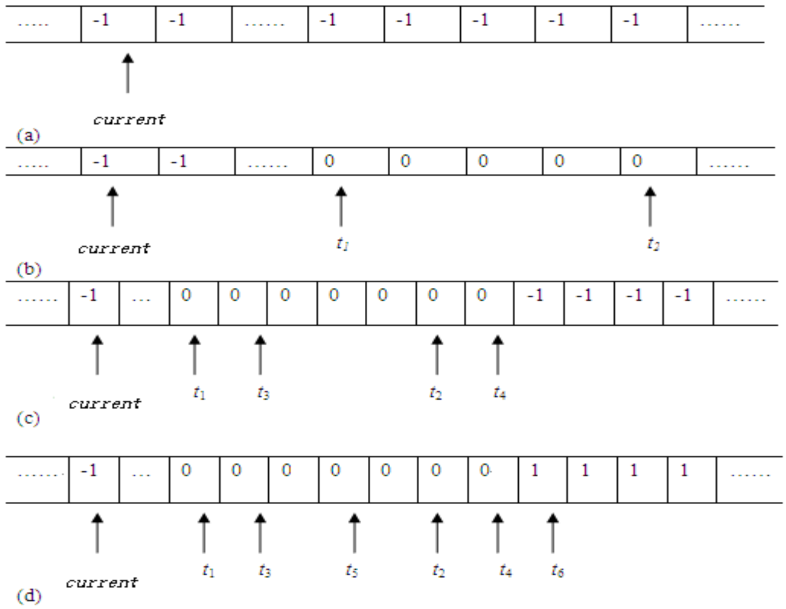

Figure 2. Maintenance Scheme of Time Slot List

(a)At initial time, the list is empty, namely, the intersection is idle, the pointer current points to the current state of traffic lights, the pointer current moves forward (right) to a position every 1 second, the traffic lights refresh once every 1 second. (b) A vehicle which drives from east to west is close to the intersection, the scheduling model calculates it should arrive at the intersection at time of t1, and leave at the moment of t2, so the numerical value changes from- 1 to 0in the time slot during t1 and t2, indicating the driving direction is from east to west in this period of time. (c) Later, a vehicle which drives from east to west is close to the intersection, the scheduling model calculates it should arrive at the intersection at time of t3, and leave at the moment of t4. It can be known from the query time slot list of the scheduling model that during the time of t1 and t2, the driving direction at the intersection is from east to west, so it allows two vehicles drive through the intersection during the time of t1 and t2 when the driving time from east to west is extended to t4. (d) A vehicle from south to north is close to the intersection, the scheduling model calculates that it should arrive at the intersection at the moment of t5, it can be known from the time slot list that the driving is permissible from east to west; the driving is prohibited from south to north at the intersection at the moment of t5; and in the scheduling model, the moment of t6 which is close to the t4 is set to be north-south traffic passage, at the same time, the model informs the vehicle to adjust its speed so as to arrive at the intersection at the moment of t6.

The specific working process of the traffic light scheduling model is as follows:

step1. If the vehicle queue is not empty, the first vehicle x is selected;

step2. Calculate the latest time point t1 which can be offered for the vehicle to drive according to the information submitted by the vehicle (such as the distance, Sx (t0) and the speed vx (t0), *etc*.) and the time slot list;

step3. t2=t1-t0， is returned to the vehicle, and the vehicle is removed from the queue;

step4. Update time slot list, indicating that the intersection is occupied by a vehicle at this period of time, repeat step1.

The vehicle which has accepted scheduling in the process of driving toward the intersection has unexpected situation (such as anchor, the owner changing the destination, and so on and so forth), the vehicle will inform the traffic lights, the allocated time slot will be voided, the vehicle re- join the queue for a second scheduling.

Assuming the application submission time of the currently being processed vehicles X is t0, the current speed is vx(t0), the maximum permissible speed is vmaxx, the distance between the vehicle and the intersection is sx(t0), the width of the intersection is L, the turning speed is vrx.

The earliest time of Vehicle X arriving at the intersection is:

$$t_1 = t_0 + \frac{s_x(t_0)}{vmax_x} \tag{5}$$

In the case of a straight line, the time the vehicle passes through the intersection is:

$$\Delta t_1 = \frac{L}{vmax_x} \tag{6}$$

In the case of turning corner, the time the vehicle passes through the intersection is approximately:

$$\Delta t_2 = \frac{\frac{1}{2}L^*\pi}{vr_x} \tag{7}$$

Read through the time slot list, the initial time t1 allowing Vehicle X to drive and the passing time t2 can be found. The time Vehicle X arrives at the intersection at the original speed is:

$$t_3 = t_0 + \frac{s_x(t_0)}{v_x(t_0)} \tag{8}$$

If t2 = t3， indicating the speed is not needed to be adjusted， the scheduling ends. Otherwise, the time of Vehicle X returns is：

$$\Delta t = \begin{cases} 0, & \frac{S}{t_2\text{-}t_0} < V_{min} \\ t_2\text{-}t_0, & \text{其他} \end{cases} \tag{9}$$

Wherein, Vmin is a threshold, too slow speed of the vehicle will increase energy consumption. When $t_2\text{-}t_0$ is large enough, indicating it will be a long time for the vehicle to drive through the intersection, at this point, the vehicle will drive toward the intersection and wait for the green light in a more fuel-efficient way (idling, for example).

4. Experiment

The simulation environment is NCTUns6.0 [14], the topology is shown in Fig 3. The road in the experiment consists of an intersection and two closed loops, five vehicles are randomly placed, the driving route of each car is randomly decided, the three aspects of speed, fuel consumption and traffic efficiency are compared between the improved model and traditional model.

The vehicle will generally park at yellow light, so the traditional model of this paper will omit yellow light, the switch time period of traffic lights red, green is set to be 30 seconds. In the improved model, the vehicle will establish communication with traffic lights at 100 meters away from the intersection, traffic lights control the time the vehicle arriving at the intersection, and turns on the green light when the vehicle arrives in the corresponding direction. Simulation time is 400 seconds; a sampling of vehicle driving situation is conducted every 0.6 seconds.

Taking into account the speed limit of the vehicle in the city to be generally 40km/h~80km/h, the maximum speed of the vehicle in this paper is set to be 65km/h. If the pavement is asphalt and dry, the maximum deceleration of the vehicle is8.5m/s2[15]; the maximum acceleration is 3m/s2.

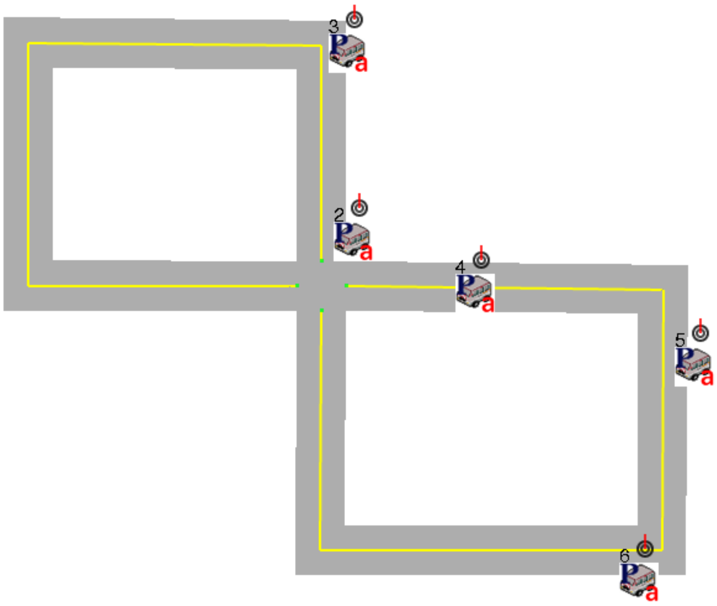

Figure 3. Topological Diagram of Simulation Experiment

4.1.Driving Speed

Figure 4 is the contrast data of average distance of the two models. It can be known within 400 seconds, the vehicle in the traditional model drives 4319. 23 meters on average, the vehicle in the improved model drives 5483.79 meters on average, and the improved model increased by 26.96% than that of the traditional model.

Table 1 is the speed comparison of the 2 models (the ID of the vehicle starts at 2, ID1 is the number of traffic light). It can be known from the table that the speed of each vehicle in the improved model is obviously improved compared with that in the traditional one. In the traditional model, the speed ranges in 10.06m/s~11.62m/s, the standard deviation is 0.520; in the improved model, the speed ranges in 13.58m/s~13.86m/s, the standard deviation is 0.107,

The speed gap among different vehicles is smaller in the traditional model. This is because the speed in the traditional model is greatly affected by the route and the timing going through the intersection, the time needed for different vehicles going through the intersection is different. While in the improved model, the scheduling of the intersection gives full consideration to the needs of each vehicle, makes a fair scheduling scheme, so the speed gap between vehicles is smaller.

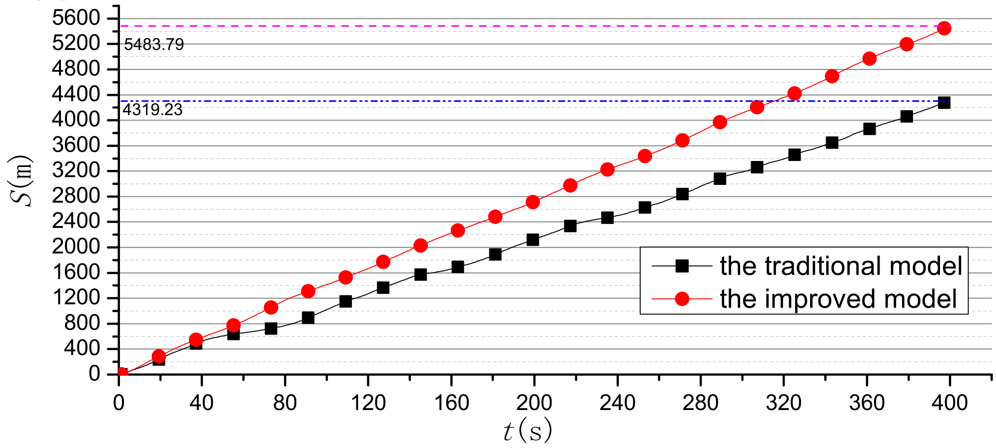

Figure 4. Average Distance of the Vehicles in the Two Models

Table 1. The Speed Contrast Between the Traditional Model and the Improved Model

	Traditional model		Improved model		
Vehicle ID	Driving distance（m）	Average speed（m/s）	Driving distance（m）	Average speed（m/s）	Percentage increase compared with the traditional model
2	4644.64	11.62	5425.72	13.58	16.87%
3	4201.88	10.52	5483.16	13.72	30.41%
4	4313.34	10.79	5446.26	13.63	26.32%
5	4019.84	10.06	5526.23	13.82	37.38%
6	4416.46	11.05	5537.58	13.86	25.42%

Figure 5 is the detailed speed contrast of Vehicle 3 in two models. It can be known from it that the average speed of Vehicle 3 in the improved model is obviously higher than in the traditional one. The speed standard deviation in traditional model and in the improved model is respectively 6.27 m/s and 4.60m/s, and 4.60 m/s, indicating the speed change of the vehicles in the improved model is smoother. In the two models, the top speed of Vehicle 3 is set to be a maximum of 65 km/h (*i.e.*, 18 m/s). Through the intersection, the vehicles need to slow down, but the deceleration range is not the same in the two models. In the traditional model, Vehicles 3 goes through the intersection 4 times, including 3 times full stop because of the red light; in the improved model, Vehicle 3 goes through the intersection 6 times, there is no parking or waiting. Going through the intersection quickly and without waiting is the main reason for the speed improvement in the improved model.

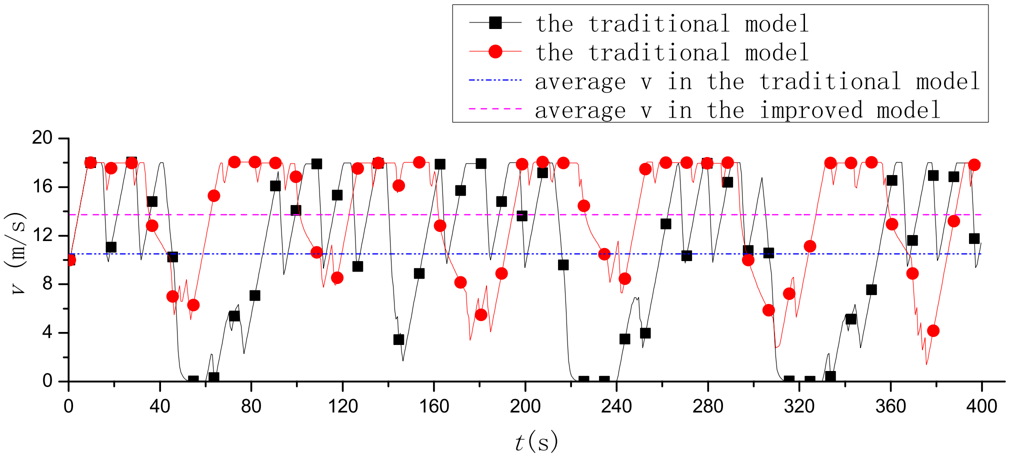

Figure 5. Speed Contrast of Vehicle 3 in the Two Models

4.2. Fuel Consumption

Fig 6 is the measured fuel consumption curve of New Regal 2.4 flagship version.

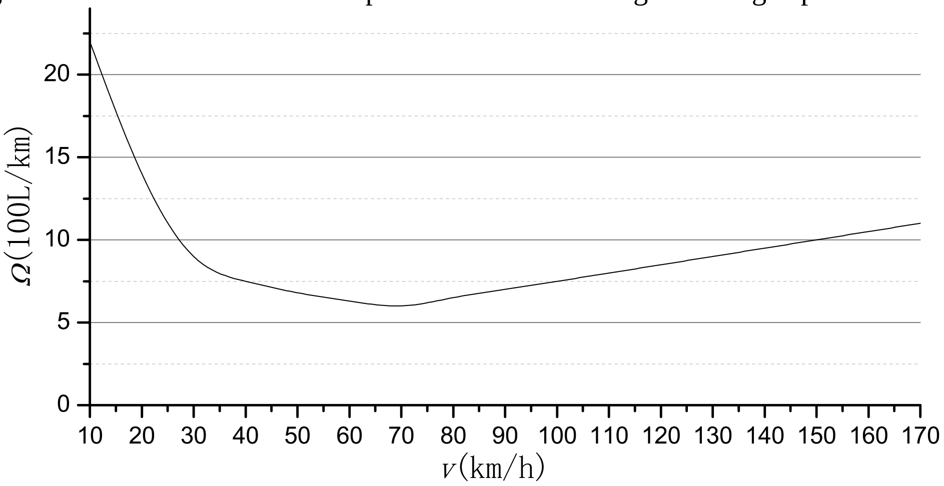

Figure 6. Minimal Fuel Consumption Curve of New Regal 2.4 Flagship Version

It can be known from the above figure that in the appropriate speed range (40km/h~90km/h) , the fuel consumption of vehicle is relatively low, and fuel consumption at a low speed is very high. Therefore, to control the vehicle's running speed, to avoid frequent braking and starting is an effective way to reduce fuel consumption.

The fuel consumption- speed function is established as follows according to Figure 6:

$$= -1.403e - 005*v^2 + 0.07207 * v + 284.7 * \left(\frac{1}{v+1}\right) -2.402 \quad (10)$$

Wherein, v indicates the speed, its unit is Km/h; Ω indicates the fuel consumption, its unit is L/100km.

Figure 7 compares the average fuel consumption of the two models. From it, we can know that the fuel consumption of the vehicle in the improved model is significantly reduced compared with that in the traditional model, and the distance of the vehicle is farther with more obvious advantage. At the end of the experiment, the average fuel consumption in traditional model is 297.787ml, while the average fuel consumption in the improved model is 273.805ml; the fuel consumption in the improved model is saved by 8.9% compared with that in the traditional model.

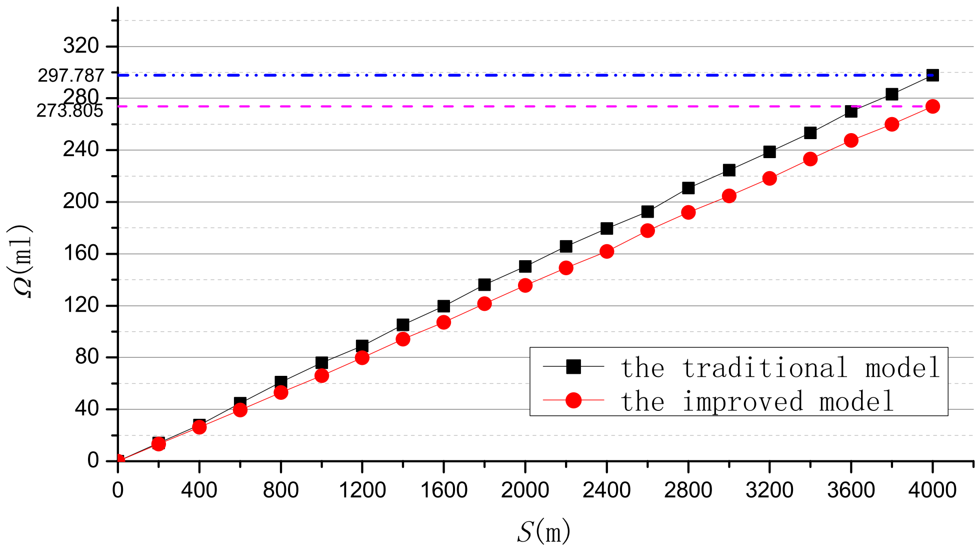

Figure 7. The Average Fuel Consumption Contrast in the Two Models

Table two is the fuel consumption contrast of per vehicle in the 2 models. It can be known that the greater driving distance is improved, the more obviously the fuel consumption is saved. This is because the fuel consumption and the speed are in inverse proportion under the current fuel consumption model (Formula 10) and speed limit (65km/h). The standard deviation of the average fuel consumption of 5 vehicles in the improved model is 0.0414L/100km, the standard deviation of average fuel consumption of 5 vehicles in the traditional model is 0.0866L/100km, which indicates that the fuel consumption of different vehicles in the improved model is more average and the scheduling is fairer.

Table 2. Fuel Consumption Contrast of Per Vehicle in the Two Models

	Traditional model			The improved model			
Vehicle ID	Driving distance (m)	Fuel consumption (ml)	Average fuel consumption (L/100km)	Driving distance (m)	Fuel consumptio n (ml)	Average fuel consumption (L/100km)	Percentage of average fuel consumption savings
2	4644.64	353.683	7.6149	5425.72	389.79	7.1841	5.66%
3	4201.88	324.22	7.7161	5483.16	391.254	7.1355	7.52%
4	4313.34	332.082	7.6989	5446.26	390.409	7.1683	6.89%
5	4019.84	315.819	7.8565	5526.23	390.754	7.0708	10%
6	4416.46	336.788	7.6257	5537.58	393.378	7.1037	6.85%

The coordinate (X, Y) of driving track of Vehicle 3 and the instantaneous speed at each coordinate point are recorded; the instantaneous fuel consumption figure of Vehicle 3 in the two models can be obtained by combining Formula (10), shown in Figure 8 and Figure 9. It can be known from Fig that the instantaneous fuel consumption of the vehicle at the intersection is obviously higher. Due to the low loss rate, the fuel consumption of the improved model is much less than that of the traditional model. At the non-intersection, the difference of the instantaneous fuel consumption of the two models is not significant. Figure 10 shows the fuel consumption statistics of Vehicle 3 after driving every 200 meters, in the condition of driving 4200 meters, the fuel consumption of Vehicle in the traditional model and improved model are respectively 324.222ml 292.824ml, and the improved model save the fuel consumption of 31.698ml. In the traditional model, Vehicle 3 parks 3 times, but it parks 0 times in the improved model, the reduction of vehicle parking can significantly reduce fuel consumption.

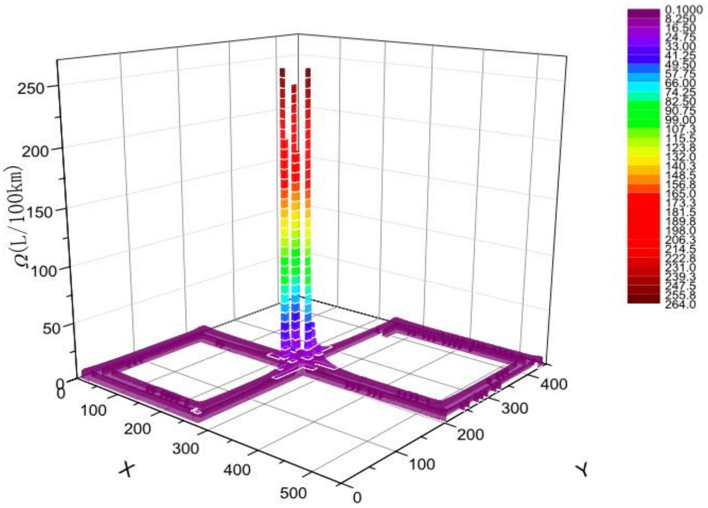

Figure 8. Instantaneous Fuel Consumption Diagram of Vehicle 3 in the Traditional Model

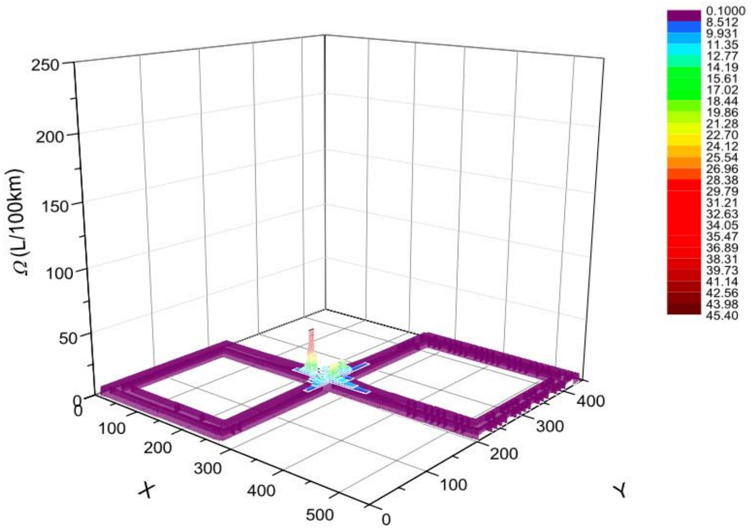

Figure 9. Instantaneous Fuel Consumption Diagram of Vehicle 3 in the Improved Model

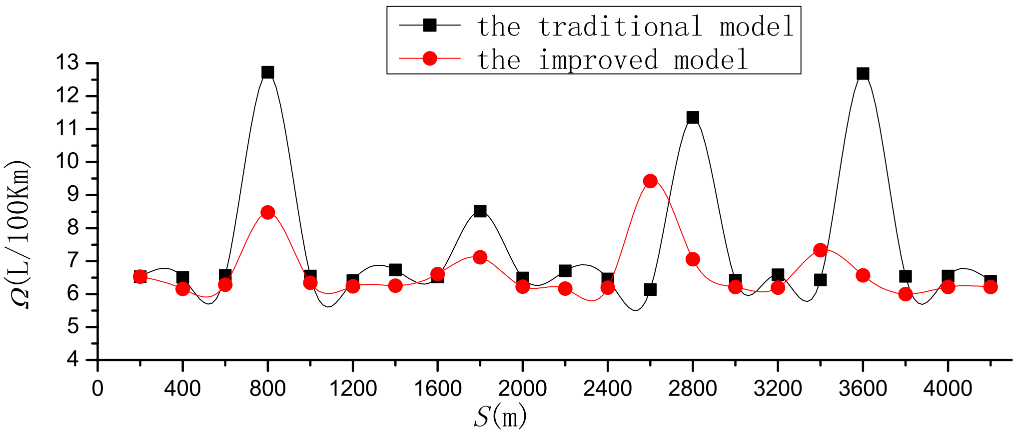

Figure 10. Fuel Consumption of Vehicle 3

4.3.Traffic Efficiency

Figure 11 shows the number of the vehicles waiting at the intersection. The intersection which has vehicles passing through or waiting at it is called a busy state, otherwise it is idle. It can be known that the improved model can greatly reduce the number of vehicles waiting for traffic at the intersection; in the traditional model, the times of parking is 15, on average, each vehicle parked 3 times, the vehicles in the improved model did not park.

The idle / busy state of the intersection is shown in Figure 12. In the traditional model, the traffic lights switch 13 times between busy state and idle state in 400 seconds, the total working time (busy state) is 276.6 seconds, 23 vehicles passed, the average vehicle / working time ratio is 0.083 / second. In the improved model, the traffic lights switch 24 times, the total working time is only 230 seconds, 31 vehicles passed. The average vehicle / working time ratio is 0.135 / second, compared with the traditional model of 62%. The switch of traffic lights in the working state in the improved model is more flexible, the time allocation of red and green lights is more reasonable, the road utilization rate is higher.

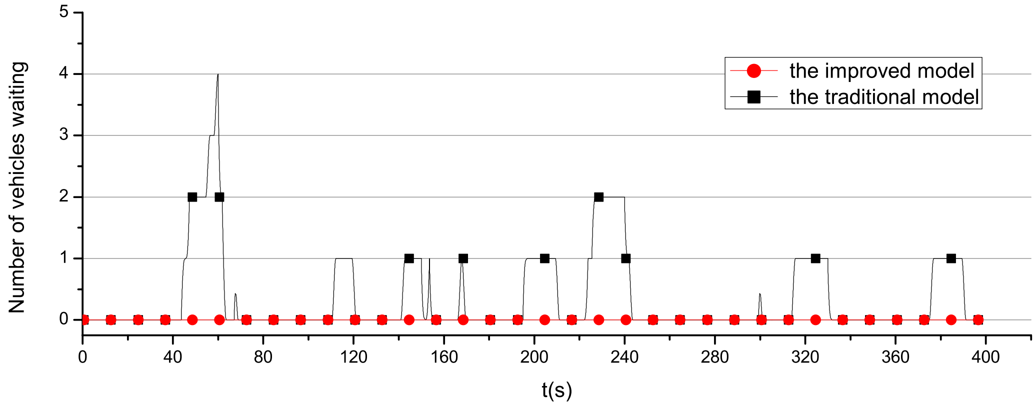

Figure 11. Number of Vehicles Waiting at the Intersection

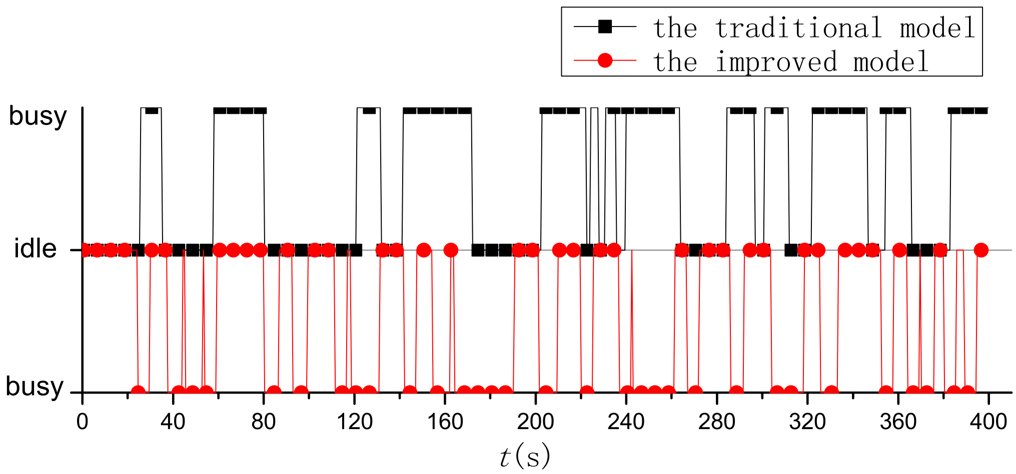

Figure 12. Idle / Busy State at the Intersection

5. Conclusions

On the basis of VANET and automatic driving, a new type of intersection scheduling model is proposed. Its key is to establish a new kind relationship of vehicle - traffic lights, so that vehicles and traffic lights can adapt to each other, achieving the purpose of saving time, energy saving and improving road utilization. The experimental results show that the improved model has greatly improved in energy consumption, traffic speed and road utilization compared with the traditional model. The model established in this paper is relatively simple, only takes the simple two-lane intersection into consideration, and doesn't take the weather and road conditions into consideration too much. And the vehicle type in this paper is also relatively simple. But the algorithm presented in this paper is a general framework, the complex conditions can fully be realized by the extended algorithm. Due to professional knowledge limitations, the modelling of fuel consumption of the vehicle is not complete, but it does not affect the correctness of the conclusion of this paper, it may have some errors in the numerical value.

The next step is to introduce the motorcade model; the vehicles form the motorcade through the workshop communications, the scheduling unit is converted from a single vehicle into a motorcade. Since there are only 4 data channels for the 802.11p protocol working at the same time, all vehicles cannot accept the scheduling simultaneously. Therefore, a better channel allocation scheme is needed. The scheduling unit is converted from the single vehicle to the motorcade, reducing the number of scheduled units to a certain extent, thereby, solving the problem. At the same time, considering the different road and vehicle types, the establishment of a diversified scheduling model is also the focus of the next research.

Acknowledgements

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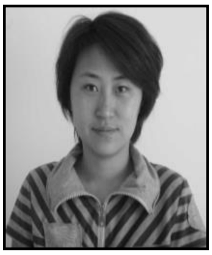
Authors



Dan Shao, College of Computer Science and Technology, Changchun University, Changchun 130022, China

Jianan Wu, College of Computer Science and Technology, Changchun University, Changchun 130022, China

