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There Is A Will, There Is A Way

--A new mechanism for traffic control based on VTL and VANET

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***Abstract*—Traffic light is regarded as one of the most effective ways to alleviate traffic congestion and carbon emission problems. However, traditional traffic light cannot meet the challenges in traffic regulation posed by the fast growing number of vehicles and increasing complexity of road conditions. In this paper, we propose a dynamic traffic regulation method based on virtual traffic light (VTL) for Vehicle Ad Hoc Network (VANET). In our framework, each vehicle can express its "will"—the desire of moving forward—and share among one another its "will"-value and related traffic information at a traffic light controlled intersection. Based on the traffic information collected in real time, the virtual traffic light in our scheme can be adaptive to the changing environment. We conducted a number of simulation experiments with different scenarios using network simulator NS3 combined with traffic simulator SUMO. The results demonstrate the viability of our solution in reducing waiting time and improving the traffic efficiency.**

Keywords- VANET, Virtual Traffic Light, Network Simulation, NS3

I. INTRODUCTION

In recent years, transportation systems in many large cities have been gradually overwhelmed by the explosively growing number of vehicles and limited capacity of road system. On one hand, traffic accidents and traffic jams frequently happen, especially in developing countries. On the other hand, traditional traffic light systems that have traffic lights to make fixed-cycle traffic signals at the intersections cannot perform well, which may deteriorate the situation during traffic jams and lead to huge waste of time. According to the report released by Beijing Transportation Committee in 2013, the average time of traffic jam is around 1 hour and 55 minutes during weekdays. In addition, the maintenance of traffic lights will cost significant amounts of resources including money and manpower. Thus it becomes urgent to design new mechanisms to bring high assurance and efficiency to the traffic system.

With the emergence of Vehicular Ad-Hoc Network (VANET) technology, a number of mechanisms have been proposed to improve traffic control efficiency and driving safety. However, none of those mechanisms can be used in any scenarios effectively. And very few of them have considered the driver's wish. Drivers who have something urgent will have a higher priority to go across the intersection. Such a behavior would make VTL more intelligent as it can meet social demand.

Due to the weakness of the current traffic light system, for example, poor adaptability to deal with dynamic changing traffic flow, and the lack of efficient light changing method, it is imperative to develop a new traffic regulation mechanism to reduce consumption of resources and meanwhile improve traffic especially during traffic congestions.

In this paper we propose a new method to address traffic congestion problem by using virtual traffic lights (VTL). When vehicles are approaching the same intersection, they pick one of them as the leader for the intersection. The leader will act as temporary traffic light infrastructure, and then traffic light information will be created and announced by it. Our method take in account the real-time information of traffic flow, each vehicle's driving conditions and drivers' will-value, and dynamically adjust the state of traffic lights to control and relieve traffic congestions. In our method, the traffic light control schedule can be quickly changed to meet the needs of most vehicles in the crossroad based on the current traffic conditions. If some drivers are not in a hurry, they can set their will-value to a lower value and let those drivers who have something urgent go first. Our method also guarantees that the vehicles in sparse lanes will not wait forever but receive a fair consideration.

To achieve high assurance of traffic control, we try to improve the efficiency of each vehicle in the system without large sacrifice of fairness. At the same time, our fairness mechanism can also ensure the correctness of the traffic control protocol. In any given road intersection, our proposed method can ensure that no vehicle will waste time for an empty traffic lane and no vehicle will wait for more than five minutes in a single intersection if the road has not been blocked or jammed. Although the waiting time improvement is hard to accurately calculate, the experiment results corroborate the efficiency of our mechanism. We have run the simulation many times with thousands of vehicles inside the scenario; every vehicle had passed the intersection in a pre-set threshold and the average waiting time of all vehicles had decreased significantly.

The remainder of this paper is organized as follows. In the next section, we review related work on traffic lights control and the VTL model. In Section III, we describe an approach to change the traffic lights dynamically. We carry out simulations using well-known traffic simulator SUMO

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and network simulator NS3, and then analyze simulation results to verify our solution in Section IV. Finally, we conclude the paper in Section V.

II. BACKGROUND AND SCHEME REVIEW

A. Background

Controlling the traffic flow of intersections is the key to keep traffic smooth in large cities. Previous researches mostly focus on traffic lights controlling, including timing system and sensor system. Timing systems include single stage timing controlling and multi-stage timing controlling. The former uses only one timing plan to control traffic lights while the latter performs different plans at different hours.

The phase time of traffic lights is usually based on historical data. In practice, as traffic flows at intersections are fast-changing and difficult to predict in real time, phase times of traffic lights are often preset to fixed values, instead of being dynamically adaptive to the traffic condition. However, a fixed time traffic light mechanism often cannot meet the demand of efficient regulation in a highly dynamic and complex traffic environment. For example, vehicles must wait for their turns to move, even though there is no vehicle crossing from the green-lighted intersection.

Sensor based controlling systems usually include cameras or vehicle monitors at the entrance of intersections and they decide the traffic lights based on the traffic situation of the intersection. Due to short lifespan, high energy consumption, and high maintenance cost make sensor based controlling systems often are only available at some busy intersections.

B. VTL scheme

Virtual traffic light is based on VANET [1][2][3]. VANET is an Ad-Hoc Network in which every vehicle can be seen as a mobile node, and each node is equally important. A node of VANET can be a router and a host simultaneously. Transmission path can be established between two nodes and information is transmitted through multi-hop routing. Therefore, VANET is a dynamic mobile network.

VTL was first introduced by Michel Ferreira et al. in [4]. The authors argue that VTL not only can improve the efficiency of vehicles and reduce costs and failure rates, but also can ease congestion at the intersection without the installation of traffic lights.

VTL runs as follows [4]: When vehicles are reaching the same intersection, they should come to an agreement to pick one as the leader for an intersection. The leader will act as temporary traffic light infrastructure, and then traffic light information will be created and announced by it. Others will follows leader’s instructions and comply with the traffic lights.

There are two crucial features in this situation: One is that the leader shows red light, stopping at an intersection when leading it. The other one is that the leader vehicle is the nearest vehicle to the intersection.

In the time of the leader lifespan, traffic light will maintain the same signal until it finds the road with the green light has no vehicles or it reaches the time limit. Then it will change the light phase and a new leader will be elected.

The new leader is the closest vehicle in its lane to the intersection before the red light. If no other vehicle can be found on the road, VTL is not needed anymore.

Some researchers have proposed a number of improvements about VTL. For instance, in [5], Wantanee Viriyasitavat and Ozan K. Tonguz considered how emergency vehicles work at an intersection in order to facilitate emergency response operations. The leader will give priority to the emergency vehicle, so that the emergency vehicle will be able to pass the intersection as soon as possible. Pedro M.d’Orey assessed in [6] the condition about carbon emissions mitigation, making considerable reduction on CO_2. Authors of [7] considered about a graphical user interface. It demonstrates a new Human Machine Interface to inform driver virtually the information about traffic control. The driving performance within the virtual scenario didn't have much difference with the driving performance locating physical traffic lights on it. And, how to balance the interaction between VTL equipped and non-equipped vehicles has been discussed in [8] and [9]. In [8], when the equipped vehicles come to the intersection, the virtual traffic signal will be shown on its windshield to let non-equipped vehicles know the real-time traffic. In [9], it stated a co-existence model separating the road network into two parts: roads for VTL-equipped vehicles and roads for non-equipped vehicles. Authors in [10] considered how signal fading or non-line-of-sight conditions have effects on VTL.

However, none of the schemes mentioned above considers dynamically changing the traffic light phase time according to real-time traffic. They also do not consider the driver’s actual situation and their will. No specific change method of VTL has been proposed.

III. METHODOLOGY

In this section, we describe in detail the approach to decide how traffic lights regulate their phases using information received from vehicles.

As we know, there are four basic phases of a traffic light (right turn is allowed at any time). A common four-way intersection is shown in figure 1. Each phase is composed of a pair of opposite directions. For example, the direction from north to south and the direction from south to north make a single phase. Only one phase is active at a time. The conventional way is going through the four phases one by one in a single cycle.

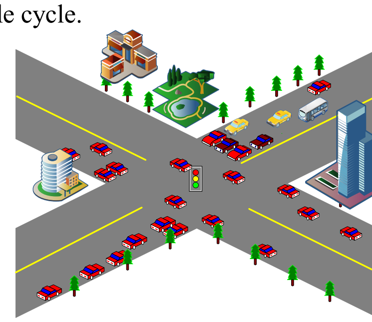

Figure 1. A Common Intersection

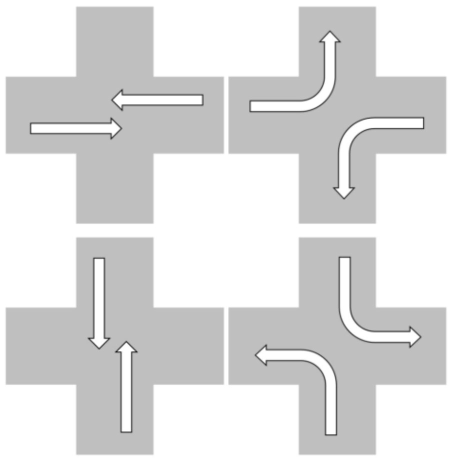

Figure 2. Four Basic State of Traffic Light (Left-hand drive)

A. Factors

We use several factors to estimate the road environment. These factors are:

Total number of vehicles on the same lane: vehicles on the same lane will expect the same phase *p*. $N_v(p)$ denotes the number of all vehicles which are waiting for the phase *p*. We can get a general idea of vehicles' distribution. In a four-way intersection, all lanes can be classified into four classes: a) north-south and south-north; b) west-east and east-west; c) north-east and south-west and d) west-north and east-south. By using this parameter we can find the heaviest lane.

Waiting time of every direction: we set this parameter $T(p)$ in every vehicle. $T(p)$ denotes how long the front-vehicle of its direction has been waiting for phase *p* since it stopped at the intersection. The longer the waiting time $T(p)$ is, the more likely it is for a traffic congestion to occur. Meanwhile, if the waiting time of phase *p* is long, vehicles in that direction will be assigned a high priority to cross the intersection.

Lane numbers of a same direction: In some busy roads, there may have several lanes for the vehicles going to the same direction. $N_l(p)$ denotes the number of lanes corresponding to phase *p*. $N_l(p)$ is helpful to calculate the density of vehicles and how many vehicles can cross the intersection within one time period.

Driver's will-value: We take the driver's thought into account. When a driver wants to change the traffic light or keep the green light longer, he can send this information to the leader vehicle. W_i denotes the will-value for the driver of vehicle *i*. $\sum W_i(p)$ is the sum of these drivers' will-value. S_i denotes that vehicle *i* has sent its will-value to the leader. N_s denotes the number of all the vehicles on these lanes which have sent will-value. W_i is graded as slight, moderate and strong, represents by 8, 9 and 10. Moderate is set as the default value. Drivers send their will-value according to their actual situation. They can send "strong" to the leader when they are very anxious. If a driver set lower value for five times in a row, it will be regarded as an absent-minded node. Then, its value will be set to the average will-value. They also can send another signal if they change their minds.

Changing-rate: The following formula indicates each direction's possibility to get a green light to permission. It consists of two parts: density and will-value. Density means the average quantity of vehicles in each direction. Will-value points out the average will-value among drivers.

$$Changing\_Rate_p = \frac{N_v(p)}{N_l(p)} * \frac{\sum W_i(p)}{N_s} \quad (1)$$

Duration of the phase occupied the intersection: D_t denotes how long it has been since the traffic light turned to green. If D_t is small, vehicles will go by fits and starts. It will produce pollutants such as PM2.5, which may have an adverse effect on human beings. Besides, for fairness consideration, D_t cannot be too big because the vehicles in sparse lanes should not wait too long.

At first, a leader is elected using a VTL scheme. It sets traffic light information and broadcasts it. Every vehicle in the scenario is assigned a unique id and equipped with Dedicated Short Range Communication (DSRC) devices. They communicate with each other by sending packets, including massage type, their id, current position and will-value to the leader. Here is the format of the transmitting packet.

Type	Vehicle Id	Lane	IP address	Will-value	Distance to intersection

Figure 3. Packet Format

Type 0 means a new leader is broadcasting its information. Type 1 means that: the information is coming from a passive vehicle to the leader. Type 2 means that will-value or the lane of this vehicle has changed. When the leader receives a packet from a passive vehicle, it will check its list. If the leader already has this vehicle's information, it will update its own data. Otherwise, it will add this new vehicle into the stack and classify it into the corresponding lane. On the other hand, if a vehicle has left the intersection, it will send a packet to the leader. Then the leader will delete this vehicle's information from the stack in order to maintain real-time and accuracy. Type 2 also acts as a response frame when it receives a Type 1 message. Type 3 means the old leader is sending information to the new leader. If the new leader has received this message, it will reply to the old leader. This is type 4. Sometimes the packet transmission path is longer than the road so that vehicles may receive packet from other intersection's leader. To prevent this, leader use type 5 to tell the vehicles whether it belongs to this intersection. If it belongs to this intersection, leader will send 1 in will-value. Otherwise, the will-value will be -1.

B. Algorithm

Algorithm 1 describes the main idea of our proposed traffic light scheduling scheme. Normally, *changing-rates* will be computed in every scheduling cycle *SC (10 seconds by default)*.

At first, it will check waiting time $T(p)$ of each phase *p*. If there exist $T(p)$ that is larger than *maxWT* (a pre-defined parameter of the maximum waiting time for vehicle), the green light will be given to *p* (line 1-4). If a phase has occupied the intersection for a period D_t longer than *maxPT* (the maximum time limit of any green light session at the intersection), the phase should be shifted to another one according to the *changing-rate* (line 8, 9). If all vehicles on the green light lane have passed the intersection or it reaches a new SC, the leader will compute a new *changing-rate*. The phase with the highest rate can use the intersection (line 10-13).

Algorithm 1. Traffic light scheduling

1: **for each** cycle in the intersection **do**
2: **if** exist $T(p) > maxWT$
3: set the green light for phase *p*;
4: reset D_t of phase *p*;
6: **else if** $D_t \geq maxPT$ **or** $Nv(current\ phase) = 0$
7: compute a new *Changing-rate* scheme;
8: **if** $D_t \geq maxPT$
9: shift the green light from the current phase to the phase with the highest priority (ignore the current one) in the new scheme;
10: reset D_t of this new phase;
11: **else**
12: release the green light to the top phase in the new scheme ;
13: **end if**
14: **end if**
15: **end for**

One thing that should be noted is that unless no vehicle is on the green light lane, each phase should last no less than 20 seconds due to environment protection and energy saving considerations. Moreover, a frequent change of traffic light will lead to low traffic efficiency.

The new changing-rates determine whether the traffic light state should be changed. If the green light is given to a lane which the leader is on, the vehicle nearest to the intersection in the lane with the lowest rate will become the new leader. If the appointment packet has not been sent to the new leader successfully, it will resend the packet until reaching a time limit. Note that passive vehicles will also start timing if they cannot receive any traffic light signal. In either case, when time is up, a new leader will be elected according to the VTL rules immediately. Otherwise, the intersection will lose its leader. This will improve the reliability of the scheme. Once a new leader receives an appointment packet, it should check its current lane and corresponding intersection in case of information inconsistency with leader to leader.

Although there are not many vehicles on one lane, if they have a strong desire to change the traffic light and they all choose “strong” as their will-value, then the changing-rate will become higher.

As vehicles have passed, the changing-rate from the green light lane would decrease and the others would grow. According to the scheme, green light will be given to the lanes with highest changing-rate. The rest can be done in the same manner. Until there is no other vehicle at the intersection or on other lanes, VTL is not needed anymore.

Therefore, the change of virtual traffic light is not fixed. It is based on the real situation. Every intersection has its own sequence to change VTL no matter if it is narrow or wide. If the changing-rates are close, it will run from state 1 to state 4. Each phase is almost equal. This scheme is particularly good in some uneven traffic distribution and reduces energy consumption well. Meanwhile, it provides convenience to drivers with urgent needs.

IV. EVALUATION

The Network simulator NS3 and the traffic simulator SUMO are used as simulation platform to evaluate the proposed VTL scheme. NS3 [11] is an open-source network simulation software, built for research purposes. SUMO [12], short for "Simulation of Urban MObility", was developed by DLR in 2001. After over a decade of development, it has become a full-fledged traffic simulator [13]. We implement the co-simulation of NS3 and SUMO, letting NS3 change the vehicle’s driving route dynamically in SUMO scenario through sending instruction [14].

To verify the feasibility of the scheme, we conducted two experiments. During the first one we observed a busy intersection with uneven traffic flow. And we picked a block which includes East China Normal University and the Changfeng Park as the second simulation scenario, to observe whether the scheme can adjust various kinds of intersections and improve traffic condition. The Origin–Destination Matrices are used to generate traffic flow, which describes traffic demand arising between two places of origin and destination. We separate the road network into several traffic assignment zones. It computes a trip table according to origin and destination. Each vehicle sends the packet to the leader which includes their id, IP address, will-value and so on. In our setup, about 80% of drivers choose “strong” as their will-value, 15% of them choose “moderate”, and 5% of them choose “slight”. They can resend the packet when they hope to change their ideas. *MaxPT*, *maxWT* and *SC* are set to 120 seconds, 300 seconds and 10 seconds for simulation study.

The relevant parameters of the two experiments are mentioned below:

Table. 1. Experiment Parameters

Parameter	Value
Acceleration	3 m/s^2
Brake Acceleration	6 m/s^2
Max Speed	60 km/h
Radio Propagation Model	Nakagami model
Wireless Protocol	802.11b
Routing Protocol	AODV

The performance evaluation criteria used are the average time in the scenario as well as the average waiting time of vehicles. The first one is the average trip duration for all vehicles. The second one is the average time period for all vehicles waiting at all intersections.

A. VTL in a single intersection

We set an intersection as shown in figure 4. It is a four-way stop controlled intersection. Vertical road has four lanes, including two straight lanes, one left-turn lane and a right-turn one. Horizontal road has three lanes: left-turn, right-turn and straight lane. The traffic flow on the pair of directions of North-South and South-North is much heavier than the other three pairs of directions. On the other hand, there are few vehicles passing in the North-East or East-North directions.

We use SUMO to generate traffic flow with O/D Matrices as follows: The length of each road is 200 meters. The south-north and north-south roads are treated as busy road. Almost half of the vehicles will go through these roads. And, on the other hand, the north-east and south-west road has a low density. Only several vehicles will pass them.

We build several scenarios, shown in Table 2.

Table. 2. Vehicles Distribution (N: North, S: South, W: West, E: East)

Name / Vehicle number	N-S S-N	N-E S-W	W-E E-W	W-N E-S	Right turn
750	195*2	20*2	60*2	80*2	10*4
600	180*2	10*2	40*2	60*2	5*4
300	82*2	6*2	22*2	30*2	5*4
250	62*2	7*2	21*2	25*2	5*4
200	40*2	10*2	20*2	20*2	5*4

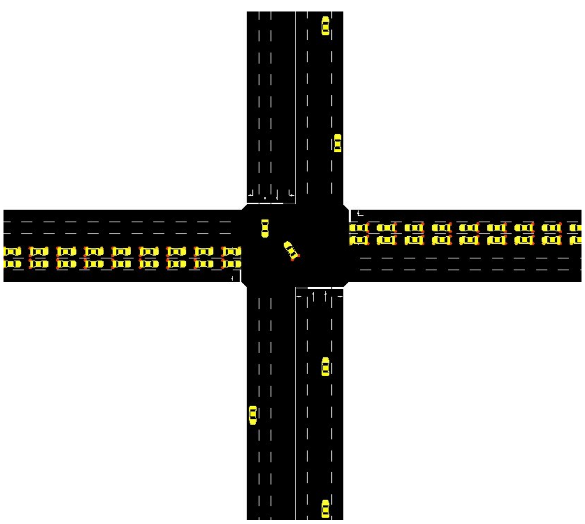

Figure 4. Experiment Scene (using SUMO and NS3)

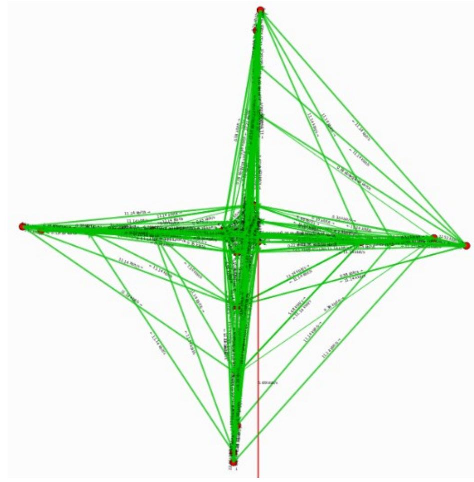

Figure 5. NS3 Packet Transmission

Vehicles go into scenario at a random time. Each vehicle has the capability of wireless communication. We use Ad-hoc On-demand Distance Vector (AODV) as a routing protocol to send packets to each other. When a leader is selected, it will broadcast itself and the information of a traffic light. Figure 5 shows that vehicles are communicating with each other.

In experiment 1, at first, with vehicles approaching the intersection, id 143 has been elected as a leader. Since it is on the west-north lane, this direction is given a red light. After 10 seconds, the leader finds that there is no vehicle on the lane. According to the scheme, traffic light should change in order to prevent wasting time. The direction with the highest rate has the green light, which is north-south and south-north. Others turn red. And the lowest rate lane, south-west and north-east, the vehicle which is nearest to the center is selected as the new leader. As the time goes on, the number of vehicles on the west-east and east-west lanes is growing quickly. When the phase time reaches 10 seconds, the rates are calculated again. Since there are too many vehicles on this lane, the phase is lasting until 120 seconds. Although the traffic light has changed several times, the north-east and south-west did not have a chance to turn green as a result of low traffic density. So, if these two directions expect a green light, their waiting time should be no less than 5 minutes.

We present the two results of the simulation: one is our scheme and the other uses the real physical traffic lights (with fixed time cycle duration) in figure 6, figure 7 and figure 8.

These figures clearly indicate that a lot of improvements on both of the two evaluation criteria if our scheme is used. We can find that compared to a periodic cycle of a traffic light changing, when the number of vehicles grows, the waiting time has decrease significantly, reducing by up to 60%.The CO_2 emission also cut by 13.27%. The average time in the scenario as well as the average waiting time of vehicles is much less than the fixed time cycle duration.

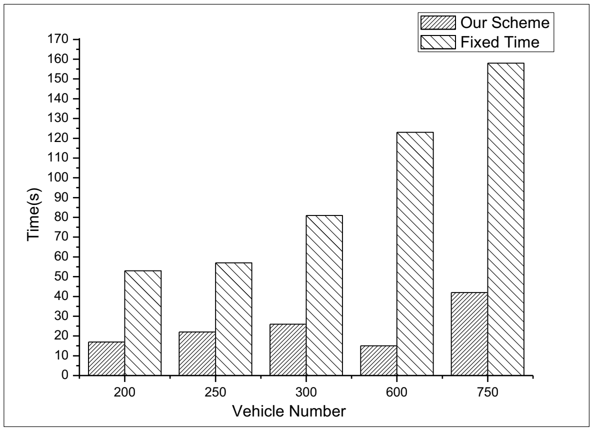

Figure 6. Average waiting time between our scheme and fixed traffic light

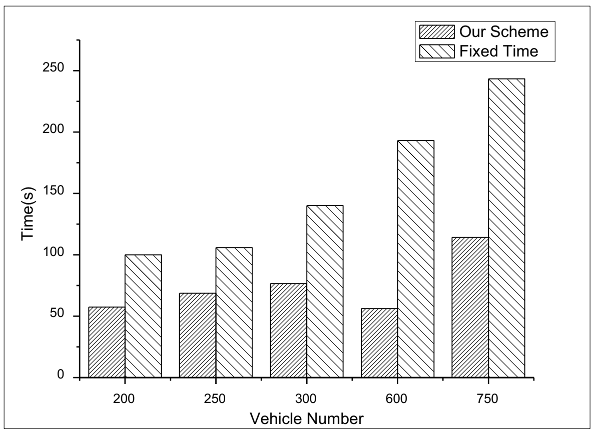

Figure 7. Average in scenario time between our scheme and fixed traffic light

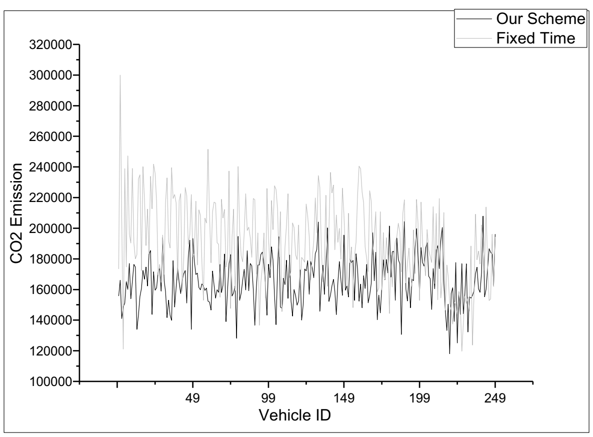

Figure 8. CO2 Emission of 250 vehicles

B. Full Routes around ECNU

We have also studies some full routes of vehicles from their origin to destination. We evaluated our scheme in the scenario of the roads around the Changfeng Park and East China Normal University (ECNU) with different types of intersections. For example, node *A*, *B*, *C*, *D* and *E* are four-way intersections. Node *a*, *b* are T-intersections. Road between node *C* and node *E* is a main road. Road between node *B* and *b* is a two-lane road. The map is shown in figure 9.

Simulation has run for 630 vehicles. Their starting places are ten main intersections. Traffic density increases rapidly within a short period of time. In the fixed time experiment, traffic light phase time is set according to the lane numbers and the real phase time.

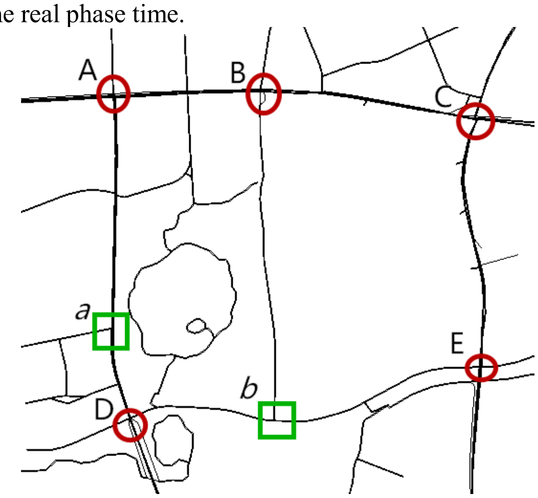

Figure 9. The map around the Changfeng Park and ECNU

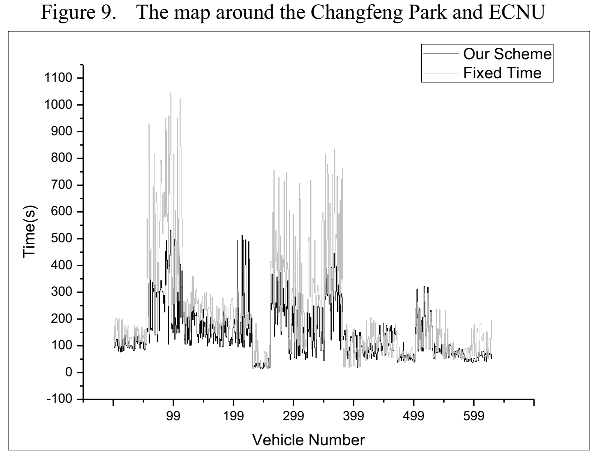

Figure 10. Vehicles Travel Time around ECNU (From origin to destination)

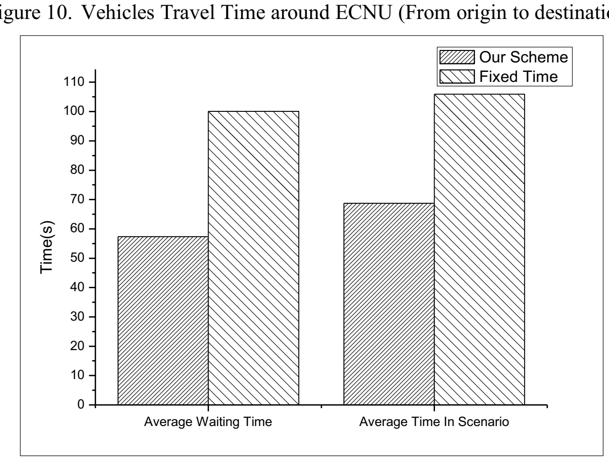

Figure 11. Average waiting time and average time in the scenario of 630 vehicles(From origin to destination)

The network effects on our scheme are also investigated by each vehicle's traveling time. The results of the simulation are presented in figure 10. We can conclude that most of the vehicle's traveling time shows a big reduction. Vehicles do not need to keep waiting when there is no traffic on the green-lighted lane. But the travel time of some vehicles increases. This is because the traffic is so light on its lanes that they have to wait for a slightly longer period. The average waiting time has fallen by about three-quarters, from 117s to 35s. The average time in the scenario went down from 219.43s to 146.46s.

Through data analysis, we have discovered that this scheme can obviously promote efficiency in various types of roads. Most of the vehicles can cross the intersection quickly and greatly reduce fuel and carbon-dioxide emissions. It is quite obvious that the number of vehicles crossing the intersection in a unit of time has raised considerably, indicating that not only the traffic jam can be significantly reduced in some busy road arteries, but also the vehicles are able to pass small streets quickly.

V. CONCLUSION

In this paper we have proposed a scheme that can be used to ease traffic congestion and decrease the cost and manpower in transportation system. We take driver's willingness into account, using a distributed collective decision mechanism based on VANET technology to control the virtual traffic light. Experiment results show that our scheme performs better than traditional fixed time traffic light and can largely decrease the average waiting time to no more than 70% of the origin record.

For future work, we plan to add emergency vehicles into the scenario, trying to balance emergency vehicles, strong will-value vehicles and ordinary vehicles. To improve the fairness, besides setting a maximum waiting time, we will also take driver's waiting time in adjacent intersections into consideration. So if a driver has waited for a long time at the previous intersection, its priority will be increased to avoid continual waiting.

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