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A Multi-Agent Traffic Control Model Based on Distributed System

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Abstract: With the development of urbanization construction, urban travel has become a quite thorny and imminent problem. Some previous researches on the large urban traffic systems easily change into NPC problems. We purpose a multi-agent inductive control model based on the distributed approach. To describe the real traffic scene, this model designs four different types of intelligent agents, i.e. we regard each lane, route, intersection and traffic region as different types of intelligent agents. Each agent can achieve the real-time traffic data from its neighbor agents, and decision-making agents establish real-time traffic signal plans through the communication between local agents and their neighbor agents. To evaluate the traffic system, this paper takes the average delay, the stopped time and the average speed as performance parameters. Finally, the distributed multi-agent is simulated on the VISSIM simulation platform, the simulation results show that the multi-agent system is more effective than the adaptive control system in solving the traffic congestion. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Traffic control, Distributed approach, Multi- agent, VISSIM, Adaptive control.

1. Introduction

As the continuous improvement of living standards, more and more people join the queues of the car owners. Meanwhile more vehicles swarm into the urbanization traffic, it greatly increases the complexity of urbanization traffic. It needs higher requirements on traffic control system, such as real-time judgment for the complex and volatile traffic state within a very short time, and real-time traffic signal plans to ease the traffic pressure. Many kinds of research methods have been applied to intelligent traffic system, which the optimization of the control signal of intersections in the traffic network is a quite effective method. The Urban Traffic System (UTS) [1-4] analyses the traffic data which was obtained by all kinds of sensors and makes the next traffic control signal plans to control traffic flows of each intersection.

For a large traffic network, during the peak periods, it must need the most effective control signal plans by using the traffic signal optimization program, which meets the priority pass of main areas under the fluency of secondary regions. Efficient traffic control based on the method of optimizing the traffic control signal can improve the traffic capacity, reduces the delay time of vehicles, the stopped time and improves the driving speed. In the face of such problems, researchers more inclined to methods of distributed control. The whole traffic system is divided into several interrelated subsystems or agents through using this method. Distributed control can effectively reduce complexity of real-time control, response time and network-induced delay [5-8].

A distributed-based model which abandons the central controller is presented by Dave and Tony [9]. In this model, there are many controllers, each of which is assigned to an intersection. Each controller can communicate with its neighbor controllers. A lot of key features which can describe traffic flows are designed in the proposed model. Therefore, the simulation of the whole traffic network is developed by using the directed graph which is composed of a large number of small controllers and key features. But, providing effective real-time control plans for a large traffic network is a very challenging distributed control problem [10], thus it is difficult to solve complex traffic problems by simply relying on the distributed technology.

With the deeper research of distributed technology, researchers introduce multi-agent system (MAS) [11-18] into intelligent traffic control systems. Each agent of MAS represents an entity of traffic network, thus the model can accurately simulate the real traffic scene. Monireh et al. described the HMAS (Holonic multi-agent system) [19] based on the concept of multi-agent system. The model of traffic system is composed of many regions and holonics. Each traffic controller is assigned to a holonic in this model. According to the scale of the holonic, a holonic is hierarchically divided into regional holonic and intersectional holonic. These interrelated holonics achieve the purpose of controlling the traffic signals with the help of Q- learning.

The work presented by Arnaud et al. introduced a multi-agent behavior model to simulate the intersection traffic flows [20]. Each "driver" in the real traffic scene corresponds to an agent of the model. This model allows the "driver" not fully conform to the traffic laws. An agent obtains crossing priorities by analyzing the performance parameters of other vehicles which enter the current intersection at the same phase. Then, in no case of confliction with other vehicles, the "driver" makes reasonable decisions. But it does not ample consider the whole traffic volumes and cannot realize overall optimization for the whole traffic network.

This paper proposes a traffic signal control system which is based on distributed model. In this system, we regard each lane, route, intersection and traffic region as different types of intelligent agents. The agents have the characteristics of autonomy, intelligence and cooperation, especially intersection agents and regional agents. It appears stronger efficiency while dealing large scale network problems. An agent only communicates with its neighbor agents (similar kinds of agents or different kinds of agents) so as to avoid too many agents. The agent makes a real-time signal plan according to the traffic data from its neighbor agents and the state of the current agent.

The paper is organized as follows. A multi-agent traffic model based on distributed is purposed in section 2, in which it introduces the entire architecture of the model and its detailed components. Section 3 presents the control process of the purposed model concluding global control and intersection control. Section 4 introduces an adaptive system. Section 5 describes the simulation process and analyses the simulation results of the multi-agent traffic system based on distributed and the adaptive system. Section 6 summarized the contributions of the paper and the future work of the intelligent traffic system.

2. Multi-Agent Traffic Model

The modeling method based on distributed divides the extremely complex and difficult problem into easy to solve sub-problems, and thus we can achieve the goal of solving the whole problem by respectively solving each sub-problem. Therefore, this paper uses the modeling idea based on distributed to model the traffic network. The whole traffic signal control problem can be divided into sub-problems which can be handled by controlling the intersections in the region. Each region and each intersection maintain the autonomy and mutual cooperation by using distributed control mode.

The sensors of traffic data acquisition are mainly inductive loop detector in this paper. Each inductive loop is assigned to a lane of an intersection, and each loop is connected with a vehicle detector. Vehicle data can be accurately detected according to the vehicle detectors and the inductive loops. Then we obtain corresponding parameters of each vehicle which enters or leaves the current intersection.

In order to accurately describe the real traffic scene, we adopt four hierarchical agents to represent different object respectively in this paper: Lane agent (LA) represents a real lane; Route agent (RA) represents a driving route from one lane to another lane; Intersection agent (IA) represents a real intersection, Domain agent (DA) represents the region containing several intersections. The lane agent sends traffic data which is obtained by the vehicle detectors to its neighbor route agents. The route agent calculates the priority of the route according to the traffic data from lane agents. The intersection agent recognizes the crossing routes through its lanes of the intersection, and then sends a request to its neighbor route agents. In this way, the route agent sends the data to the intersection agent. The domain agent sends an instruction of updating control signal plans to the corresponding intersection agent according to actual situation and parameters (saturation, intersection priority) of the intersection. Finally, the intersection agent determines whether to update its control signal plan according to the instruction and received data.

Four types of agents transmit traffic data through a transmission mechanism (we will introduce in the next chapter). Every agent can obtain real-time traffic data through this mechanism. It must ensure the stability of transmission lines; otherwise once the transmission lines are broken, IA will be unable to receive real-time data and cannot generate efficient signal plans. Finally, the whole system will lose its intelligence.

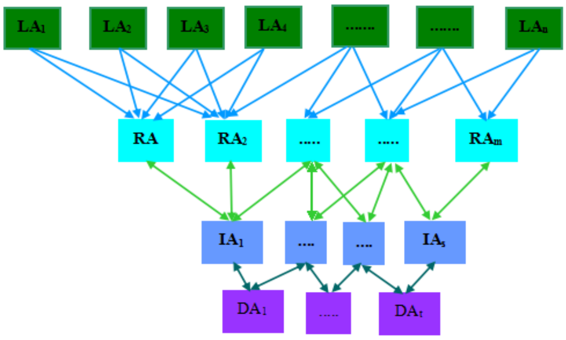

Fig. 1. Architecture of multi-agent.

2.1. Lane Agent Modeling

We describe a lane agent (LA) with the length of lane, the orientation (East, South, West, North) and the relative relation between traffic flow direction and intersection. The lane agent receives data from vehicle detectors, and then stored in a special data structure. The lane agent (LA) can be defined by a 4-tuple LA= (*LH*, N_{VMAX}, OR, EL), where:

1) *LH* is the length of lane, which determines the traffic capacity in the lane. The greater LH means the more vehicles in the lane.

2) N_{VMAX} is the maximum traffic volumes which a lane can endure. In order to balance the traffic pressure of each intersection, the traffic volumes of a lane should not be too great. The maximum traffic volumes of a lane agent can be described by (1):

$$N_{VMAX} = \frac{LH}{L+\mu}, \tag{1}$$

In (1), LH is the length of a lane, L is the average length of the vehicle in the lane and μ is the average distance between vehicles.

3) OR is the orientation of the lane which is related to the intersection. OR has four reference values (East, South, West, and North) for a crossroad.

4) EL represents the traffic flow direction of the lane. EL=1 represents that the vehicles of the lane enter the current intersection, EL=0 represents that the vehicles of the lane leave the current intersection.

2.2. Route Agent Modeling

A route agent (RA) identifies the number of the two lanes according to the flow direction, and then gets real-time LA data. Next, the route agent calculates its priority. The route agent can be defined by a 4-tuple RA= (N_S, RP, I_A, I_B), where:

1) RP represents the priority of the phase which contains several corresponding routes in the whole cycle. A cycle consists of several phases, and each phase is composed of a plurality of route agents. The higher the priority is, the longer the green signal time of the corresponding phases will become.

2) N_S is the numbers of vehicles on the route.

3) I_A is the number of the initial intersection in a route. Different routes represent different intersections.

4) I_B is the number of the terminative intersection in a route.

2.3. Intersection Agent Modeling

An intersection agent can obtain the special data sent by its neighbor route agents, and other traffic data from its neighbor intersection agents. The intersection agent takes into consideration the priorities and traffic volumes of its neighbor intersection agents so as to produce real-time signal plans. The intersection agent can be defined by a 5-tuple IA = (RI, RO, RNS, IPS, IP), where:

1) RI= {RA_1, RA_2..., RA_n} is a set of routes entering the current intersection. The intersection agent can get the information on traffic volumes of which routes will arrive at current intersection through the RI.

2) RO= {RA_1, RA_2..., RA_m} is a set of routes leaving the current intersection. The intersection agent can get the information about traffic volumes of which routes will leave current intersection through the RO.

3) RNS= {NS_1, NS_2..., NS_n} is a set of the traffic volumes of routes entering the intersection. It can calculate the total traffic volumes of intersection according to the RNS. Traffic volume is a quite important measure for signal plans.

4) IPS= {P_1, P_2... P_n} is a set of intersection parameters. The IPS of different types of intersections is different.

5) IP is the priority of the current intersection. The intersection agent obtains the value through the accumulation of the RP of each RA in the IA. The higher the priority is, the longer the cycle length of the intersection will become.

Each intersection has ML (ML arranges from 1 to 3) routes to reach a neighbor intersection. The vehicles enter the current intersection through RI and leave through RO.

In Fig. 2, the traffic flows from IAi-1 to IAi through three routes ($C_{i-1}B_{i+4}$, $B_{i+2}B_{i+4}$ and $C_{i+2}B_{i+4}$) will appear in lane B_{i+4}. The traffic flows from IA_{i+1} to IA_i through three routes ($D_{i-3}B_{i+5}$, $B_{i+7}B_{i+5}$ and $D_{i+4}B_{i+5}$) will appear in lane B_{i+5}. The traffic flows from IA_{i+2} to IA_i through three routes ($E_{i+1}D_{i-1}$, E_{i-2} D_{i-1} and $E_{i+3}D_{i-1}$) will appear in lane D_{i-1}. The traffic flows from IAi+2 to IAi through three routes ($H_{i-3}D_{i+2}$, $F_{i-2}D_{i+2}$ and $H_{i+1}D_{i+2}$) will appear in lane D_{i+2}. Therefore, we can calculate the variable quantity of the traffic volumes according to RI and RO, and then it can easy acquire the real-time traffic volumes combining traffic volumes at the end of last phase and the variable quantity. The traffic volumes in the current phase can be written as

$$N^{T} = N^{T-1} + \sum_{i=1}^{m_0}\sum_{j=1}^{m_1} RIN_{i,j} - \sum_{k=1}^{n_0}\sum_{l=1}^{n_1} RON_{k,l}, \quad (2)$$

where N^{T-1} is the traffic volumes at the end of last phase, $RIN_{i,j}$ is the number of vehicles of route j which belongs to RI in intersection i and $RON_{k,l}$ is the number of vehicles of route l which belongs to RO in intersection k.

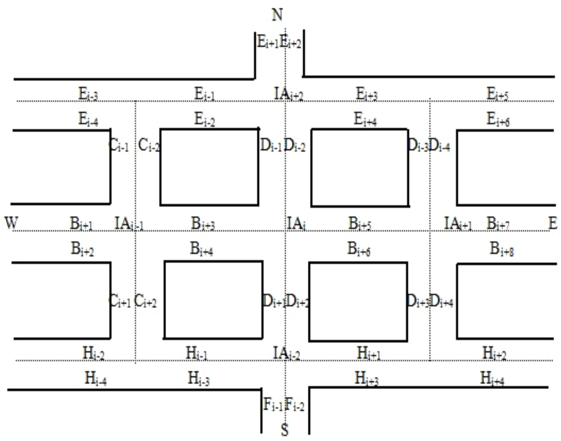

Fig. 2. Serval neighbour intersections.

2.4. Domain Agent Modeling

This paper regards a region which is composed of intersection A and its neighbor intersections as a domain agent. It can determine the size of region according to the locations of each intersection. The degree of region is proportional to its size. The domain agent produces its special information according to the traffic data in the region. The domain agent can be defined by a 4-tuple DA= (IS, IN, DP, DD), which:

1) IS= {1, 2, 3, 4... IC} is a set of the numbers of intersections in the domain agent, which IC is the number of intersections.

2) IN is the vehicle volume of the current region.

3) DP is the priority of the current region. The domain agent obtains the value by the accumulation of the IP of each intersection agent in the domain agent. The priority will change along with the change of RP and IP.

4) DD represents the degree of region, which includes horizontal degree (DDX) and vertical degree (DDY). West and east are defined as horizon. North and south is defined as vertical. Assuming that there are "e" intersections on the east of A, "w" intersections on the west, "n" intersections on the north of A and "s" intersections on the south of A, then DDX=max {e, w} and DDY=max{s, n}.

3. Multi-agent System Based on Contributed

Real-time control for a large traffic network is a complex distributed problem, thus this paper introduces MAS to simplify the whole control process. Different agents have different data transmission mechanisms, which ensure the stability of data transmission. Agents send the traffic data to its neighbours through data transmission mechanisms. And agents achieve the purpose of optimizing the control signals. The function of different agents is different, which lane agents and route agents calculate some system parameters according to the detecting data and send them to domain agents and intersection agents. Then the domain agent cooperates with intersection agents to generate coordinated signal plans.

3.1. Data Transmission Mechanism

Data transmission mechanisms are divided into two kinds: unidirectional transmission and bidirectional transmission. An agent can receive data from other agents, sends data to other agents, or both alterations. An agent which sends data is called AS, and an agent which receives data is called AR. The communication line between AS and AR is stable so as to it ensures fast and accurate data transmission, the two following points are very important:

1) The physical and logical connections between these neighbor agents must be stable. Different couples of AR and AS have different communication lines.

2) Because the data which AR needs in the data processing are obtained from AS, thus AS must send the real-time traffic data to AR quickly and accurately.

In this paper, AS (LA, RA, IA or DA) sends data to AR (RA, IA or DA) through communication lines. The process of transmission data is as follows: AR sends a request to AS and AS sends an AT (allowing transmission) signal to AR after receiving the request. AR sends the WS (waiting state) signal after receiving the AT and then be wait-receiving state, then AS starts to send data. Once data transmitting finishes, AS will send the ES (ending state) signal to AR. If AR receives the ES, it will disconnect the logical connection with AS.

The traffic data transmitting processing which the system involves is as follows. A route agent recognizes the two intersections connected to RA according to IA and IB, and then ensures which two lanes are connected to LA by OR and EL, then the sum of traffic volumes in the two lanes is the traffic volumes of the route agent. Thus, it can calculate the traffic volumes and saturation of the intersection agent according to RI and RO. Traffic data of the intersection agent which can be defined by a 5-tuple TD={CL, PI, RAN, NT, SP} includes cycle length, phase information, traffic volumes of each route agent, the traffic volumes and saturation of each intersection agent. The data transmission between intersection agents and domain agents is through communication lines.

3.2. Control Process

The whole system control includes intersection control and global control. It coordinately changes the total cycle length of each region through the global control. As different intersections have different geographic locations in a region, we can ensure relative position of intersections. Region traffic is coordinated by traffic volumes and different priorities of intersections. Meanwhile, intersection control has its own autonomy relative to the global control.

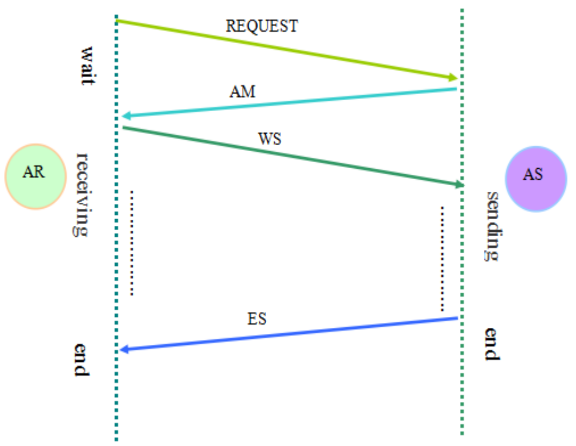

Fig. 3. Serval neighbour intersections.

3.2.1. Global Control

It identifies DC (the number of regions in the traffic network) according to a set of regions DS= {DA_1, DA_2, DA_3,. ... DA_{DC}}. Set Darray= {DN_1, DN_2,....,DN_{DC}} is derived from DS set by re-sorting as its priority of element, and the DP value of DN_1 is maximum and the DP of DN_{DC} is minimum. Fig. 4 (a) represents the regional relationship before sorting and Fig. 4 (b) represents the regional virtual relationship after sorting. We assume the based coordinate of DN_1 is (X_1, Y_1) and the based coordinate of DN_i is (X_i, Y_i). The relation between (X_i, Y_i) and (X_1, Y_1) can be written as (3):

$$(X_i, Y_i) = \left(\sum_{j=1}^{i-1} DDX_j + X_1, \sum_{j=1}^{i-1} DDY_j + Y_1\right) \quad (i \in (1, DC], j \in (1, i)) \tag{3}$$

In (3), the priority of DA_i will gradually reduce as the increasing of i, and then the total cycle length will also correspondingly reduce. The (4) describes the relationship between DA_i of the total cycle length (C_i) and the coordinate base, which θ is the average saturation value for the region.

$$\begin{cases} C_i = \dfrac{X_{i-1} \bullet Y_{i-1}}{X_i \bullet Y_i} \bullet C_{i-1} \bullet \theta \qquad (i \in (1, DC]) \\ \theta = \dfrac{\sum_{k=1}^{IC} SP_k}{IC} \end{cases} \tag{4}$$

DA sends an instruction DI= (EY, BM, C,θ) to each IA of the region, and IA determines whether to change its signal plan according to the DI.

3.2.2. Intersection Control

In the instruction DI, BM =0 represents that the saturation of the domain agent is relatively low and BM = 1 represents that the saturation is relatively high; EY = 0 represents that DI is non-mandatory action instruction and EY = 1 represents that DI is mandatory. The non-mandatory instruction and relatively low saturation of domain agent will conduct that IA selectively responses according to its condition and the saturation of the domain agent, and the mandatory instruction and relatively high saturation will conduct that IA determines whether to change the signal plan completely by itself; and once the saturation of DA reduces, IA immediately responses.

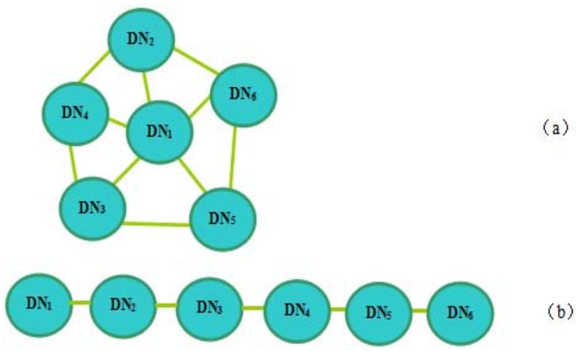

Fig. 4. The regional relationship.

How to execute the instruction is as follows. Firstly, the intersection agent establishes the logical connection with its neighbor intersection agents and sends requests to them. And then each intersection agent respectively establishes connections with its corresponding lane agents and route agents, and then they send the real-time traffic data TD_i to the agent which sends the request. When the intersection agent obtains different data from its neighbours, it will re-generate a new signal plan.

$$DI\begin{cases} EY=0\begin{cases} BM=0 & \begin{cases}\theta>SP & \otimes \\ \theta\leq SP & \oplus\end{cases} \\ BM=1 & \begin{cases}\theta>SP & \otimes \\ \theta\leq SP & \otimes\end{cases}\end{cases} \\ EY=1\begin{cases} BM=0 & \begin{cases}\theta>SP & \oplus \\ \theta\leq SP & \oplus\end{cases} \quad \oplus \text{ represents excuting the instruction} \\ BM=1 & \{\otimes \text{ represents non-responding}\end{cases}\end{cases} \tag{5}$$

Fig. 5 represents the whole process of generating the signal plan according to the traffic data from different kinds of agents. First, the intersection agent calculates the traffic volumes and the proportion of the traffic volumes of each phase through TD, and then obtains the proportion (P_i) of the phase time (PL_i) to each cycle time (CL). If P_i of the phase is 30 %, PL_i is 30 % of CL. Then, PL_i is the product of Pi and the cycle time of the original plan. Secondly, we start to loop detect each phase time. MinG (the minimum green time, which is 8 s) and MaxG (the maximum green time, which is 55 s) are introduced to detect the PL_i. If PL_i is smaller than MinG, MinG is assigned to PL_i. If PL_i is larger than MaxG, MaxG is assigned to PL_i. Then PL_i is added to CL. This step is executed repeatedly until the loop is terminated.

The third step is to calculate the reference value (CT) of the cycle time of the current intersection. According to TD, we can calculate the proportion (β) of traffic volumes of the cycle for the intersection to this region, and then CT for the intersection is the product of β and C(C which is the total cycle length of the region is included in DI). The forth step is to calculate the variable quantity (ΔPL_i) of each phase. For every phase, it obtains its priority (SRA) by the sum of the priorities of routes. The proportion (SPRA) of variable quantity of each phase can be calculated. According to SPRA and the difference value between CT and CL ($\Delta L=|CT-CL|$), the variable quantity is the product of SPRA and ΔL. Finally, we calculate each phase time according to CL and CT. If CL > CT, PL_i is subtracted by ΔPL_i; similarly, if CL< CT, PL_i is added by ΔPL_i.

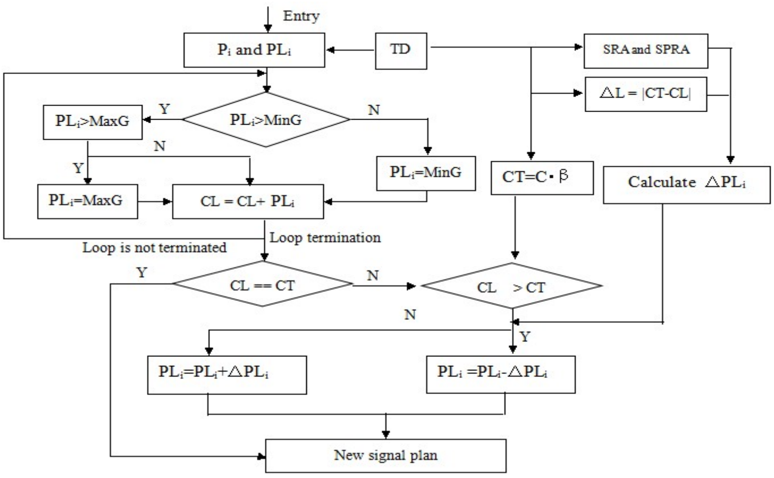

Fig. 5. Control process.

3.3. System Performance Parameters

The system that we purpose in the paper is a multi-agent system based on distributed control, and the major parameters of evaluating it are as follows: the average delay time, the average stopped time and the average speed of the vehicles. We take the VISSIM simulation platform to verify the system, the platform can detail the information of the vehicles entering or leaving the traffic network, so we can make a real-time monitoring of the whole network. The average delay time can be written as:

$$T_D = \frac{T_{TD}}{N_V} \tag{6}$$

where T_{TD} is the total delay time of all the vehicles in the traffic network, NV is the number of vehicles. The average stopped time can be written as

$$T_W = \frac{T_{TW}}{N_V} \tag{7}$$

where T_{TW} is the total stopped time of all the vehicles. The average delay time is in inverse proportion to the average speed, and it is especially obvious in a congestion traffic network. The larger the average delay time is, the more the vehicles cost time in the travel.

4. Adaptive System

To prove the effectiveness of the purposed system in real-time controlling traffic network, we make some comparison with the adaptive system which can adjust the control signal plan as the traffic volumes of the current intersection dynamically. In the adaptive system, a controller is assigned to an intersection; the controller can adjust the phase time according to the real-time traffic data of the current intersection in time.

The algorithm of changing phase time is as (8), it has been used in our own device.

$$t_p^{i+1} = t_p^i \pm \frac{V_{i+1} - V_i}{V_i} \bullet t_p^i \bullet \alpha, \tag{8}$$

where t_p^{i+1} is the current phase time of the new sign plan, t_p^i is the current phase time of the original plan, V_{i+1} represents the detected traffic volumes of the current phase in the current cycle, V_i represents the traffic volumes of the phase in last cycle and the traffic congestion index(α) is the ratio of real-time total traffic volumes to the maximum traffic volumes in the intersection.

5. Experiment Results

In order to verify the rationality and validity of the purposed traffic control system, we take the VISSIM simulation platform, and 18 bi-directional four lanes of intersections are used to simulate realistic traffic network. The traffic network is divided into 4 regions and the intersection number in different regions is not same, and then generates the priority array according to the priorities of each region. The higher the region priority is, the smaller the coordinate of the corresponding region is and the longer its total cycle time is. The intersection agents determine whether to generate new signal plans according to the instruction from domain agents. The length of a lane varies from 300 m to 500 m. Each intersection has four phases which includes two straight phases and two left-turning phases.

Basing on the VISSIM platform and VB program, the adaptive system and multi-agent system are simulated respectively to verify effectiveness.

When the traffic flows arrange is from 500 to 7000 cars/h, Fig. 6 and Fig. 7 show the experiment result of the two systems. The four curves in Fig. 6 respectively represent the average delay and the stopped time of the two systems. □ and □ represent the changing curves of the average delay time and the average stopped time of the adaptive system, meanwhile □ and □ represent the changing curves of the multi-agent system. The difference of average delay time and the average stopped time between them is very little when traffic volumes are lower than 2000 cars/h. The increasing amplitude of the average delay time and the average stopped time in the multi-agent system is obviously smaller than the adaptive system as the gradually increment of traffic volumes. While traffic volumes exceed 6000 cars/h, the advantage of the multi-agent system is not so obvious. But the system performance is still better than the adaptive system.

In Fig. 7, □ represents the tendency of the average speed in the multi-agent system and □ represents the tendency in the adaptive system. When traffic volumes are less than 1500 or more than 6500 cars/h, their performances are same approximately. But, if traffic volumes are between the two, the multi-agent system shows better system performance than the adaptive system.

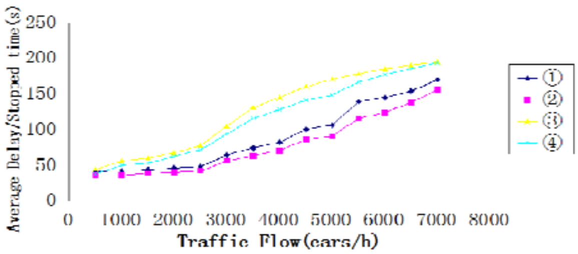

Fig. 6. The average delay and stopped time.

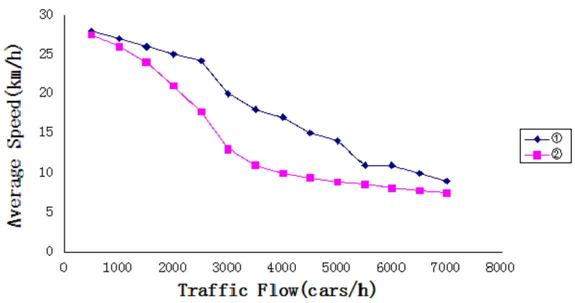

Fig. 7. The average speed.

The simulation results show that the purposed multi-agent traffic system can more effective to control and smooth the large urban traffic.

6. Conclusion and Future Work

The multi-agent system based on the distributed theory is an effective method to control traffic flows. There are different types of agent for every region, intersection, route and lane, and each agent does not communicate with over many agents, meanwhile, it closely connects with its neighbor agents. Furthermore, this design can simplify algorithm and make the whole intelligent traffic system real-time. Especially, this method does not change phase of some intersection isolatable, so it can be applied to more large realistic urban traffic networks.

Although this method is effective in large and complex traffic network. However, there are certain limitations. The intersection traffic involves the related cycle, phase and phase sequence. Especially the key phase sequence can determines discharging order and avoid vehicles collision of intersection. So, cooperative processing on the phase time and phase consequence will be the focus of future work. Each agent can adjust the phase sequence and change the phase time according to the real-time traffic data from its neighbor agents intelligently. In this way, it can extremely optimize the traffic control signal and ensures safely and smooth traffic.

Acknowledgements

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