Apply adaptive and cooperative multi-agent system to urban traffic signal control

Szu-Yin Lin, Duen-Kai Chen, and Ruey-Shun Chen

Abstract—**Traffic congestion problem in urban area is getting worse since traditional traffic signal control system could not fulfill the need of urban area traffic, therefore, dynamic traffic signal control in ITS have received increasing attention recently. In this paper, we proposed a multi-agent framework, Adaptive and Cooperative Traffic light Agent Model (ACTAM), for decentralized traffic signal control system. The framework proposed contains several modules such as Control Strategy Decision Module, Learning Module and Weighted Module. In our framework, we also provided a prediction mechanism, Forecast Module, to predict the future traffic flow in each individual intersection. Through the proposed method, dynamic and adaptive traffic signal control could be achieved, thus, total delay time of the traffic network can be reduced by 35%. Consequently, traffic congestion problem in urban area can be alleviated.**

Index Terms—**Intelligent agents, Multi-agent systems (MAS), Decentralized control, Dynamic traffic signal control**

I. Introduction

Traffic congestion problem in urban area has drawn wide attention in major cities around the world nowadays. In order to alleviate traffic congestion problem in urban area, the concept of develop ITS (Intelligence Transportation System) is widely accepted in developed countries. Advanced Traffic Management System (ATMS), which is described in ITS, includes the planning of traffic signal control system. ATMS aimed at using various technology, especially real-time traffic flow monitoring, to assist in determine traffic light control strategy. The main issue of ATMS is how to monitor real-time traffic flow and to design real-time traffic light control strategy based on its monitored traffic flow. Traditional traffic light control strategy developed during 1970's and 1980's could not fulfill the requirement of jam-packed urban traffic.

There are plenty of researches aimed at local optimal control of traffic signal system, for examples, PASSER II [1] and TRANSYT-7F [2]. Other study, for example, [3], uses linear optimization methods to solve traffic signal control problems.

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Image processing sensor system [5] has drawn wide attention in the field of ITS, the information extract from image processing sensor system can be applied to have real-time response to the incident happened. Recently, the study of apply multi-agent decentralized strategy to control an urban traffic network has draw wide attentions. Roozemond and Rogier [4] proposed a prototype using agent technology to control traffic signal system.

In this study, we proposed a multi-agent framework, Adaptive and Cooperative Traffic light Agent Model (ACTAM), for decentralized traffic signal control to improve existing system and reduce total delay time. The framework contains several modules such as Control Strategy Decision Module, Learning Module and Weighted Module. ACTAM also provided a prediction mechanism to predict the future traffic flow in each individual intersection. Through ACTAM, dynamic traffic signal control strategy can be achieved in a decentralized and collaborative way. Thus, total delay time of the traffic network can be reduced. To improve current traffic signal control system adopted in urban area, we have to come up with a more efficient solution. Traffic signal control system based on multi-agent technology out performed the traditional method in providing real-time and proactive response to dynamic traffic flow. Traffic signal control agents collaborate through communication and coordination mechanism. By analyzing historical data, the proposed framework is capable of learning and adjusting its control strategy. Therefore, flexibility of the framework can be achieved. The simulation result supported our hypothesis in that Multi-agent systems can improve the efficiency of traffic signal control system.

The rest of this paper is organized as follows. In the next section, we review previous studies attempts to solve the traffic signal control problem. Section 3, then presents the framework, ACTAM, proposed in this study. Next, section 4 describes experimental results and discussion about the result. Conclusions are summarized in section 5.

II. Literature review

PASSER II [1] and TRANSYT-7F [2] aimed at local optimal control of traffic signal system. Both of the studies tried to find out optimal solutions for local traffic signal control system in each intersection.

Traffic signal system can be categorized into 3 classes, fixed time signal, traffic-actuated signal, traffic-adjusted signal.

Fixed time signal means that controlling the traffic light by predefined timetable. In traffic-actuated signal, cycles, signal phases, signal intervals of the traffic light are defined in controllers and related devices. Traffic-adjusted signal is adopted by new style traffic control signal system; it combined the advantages of both fixed time signal and traffic-actuated signal. Through placing sensors in artery, the sensors will send monitored traffic data to master controller. Master controller then calculate and periodically distribute appropriate traffic signal control strategy (represented by signal cycle, signal phase, signal interval) to signal controller in each individual intersections.

Researchers involved in agent research have offered a variety of definitions, here, we adopt the definition provided by Russell and Norvig [7]," An agent is anything that can be viewed as perceiving its environment through sensors and acting upon that environment through effectors." In MAS, the research focused in the interaction in between agents. Coordination, negotiation, cooperation are three common ways of how agents communicate with each other.

The domain of traffic signal control is well suited to multi-agent based approach because of its geographically distributed nature. Roozemond and Rogier [4] proposed a prototype using agent technology to control traffic signal system. Ferreira et al [6] also present a multi-agent decentralized strategy to control an urban traffic network. In the approach proposed in [6], each agent optimizes a traffic index based on its local state and sensors, and information coming form adjacent intersections.

III. MAS FOR TRAFFIC SIGNAL CONTROL

In this section, we describe the proposed framework and components contained inside the framework. As shown in figure 1, multi-agent systems for traffic signal control framework consist of 3 parts.

- IIA（Intelligent Intersection Agent）：It is in charge of autonomy control of the traffic light in an intersection.
- SM（Sensor Module）：Collecting real-time traffic flow information for IIA.
- Traffic Light ：used to regulate traffic flow.

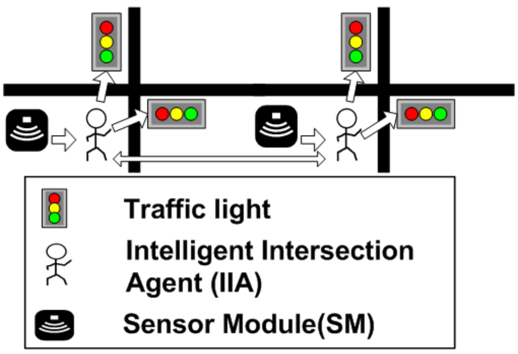

Fig.1 Multi-agent system for traffic signal control framework

Urban traffic relies highly in the quick response of control strategy for traffic light control system in each intersection. The information flow in ACTAM can be described as follow:

- First, the sensor module is used to monitor the traffic flow and send the traffic flow data to IIA.
- IIA then communicates and exchanges related information with the IIAs in the adjacent intersections.
- After collect all the information needed, IIA started to generate appropriate traffic signal control strategy for the specific traffic signal.

The information flow formed a closed loop as figure 2 presented.

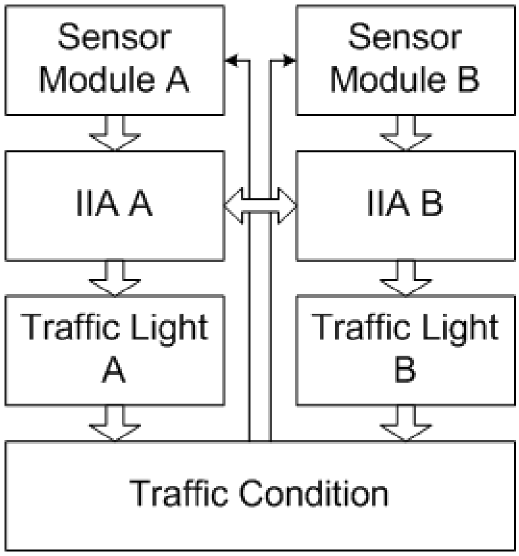

Fig. 2 Flowchart of Multi-agent system for traffic signal control

IIA collects the current traffic flow situation through Sensor Module. The data is kept in IIA's Data Process Module. IIA communicates with other IIAs in the adjacent intersection by Communication Module. After all the information needed was gathered, Learning Module, Forecast Module, Weighted Module then generates results according to its purpose (the detailed description of these components are discussed in the next paragraph). The results then delivered to Control Strategy Decision Module, where the traffic signal control strategy is made.

Components consists in IIA can be further divided into 3 categories. The functions of each component consist in IIA is briefly described in following paragraph.

Layer1, Data Layer, include Communication Module and Data process Module. Communication Module is in charge of exchange related traffic data with other IIAs, in other words, Communication Module is responsible for agent's interaction. Communication Module exchange data through KQML (Knowledge Query and Manipulation Language), KQML is a language and protocol for exchanging information and knowledge for two or more intelligent systems to share knowledge in support of cooperative problem solving. Data Process Module is a database; data involved in the process of IIA are stored here. Data stored in Data Process Module include fix data and calculated data. Fix data consists serial number of adjacent intersections, distance from adjacent intersections etc. Calculated data are from Learning Module, detail about calculated data is further discussed in paragraph explaining how Learning Module works.

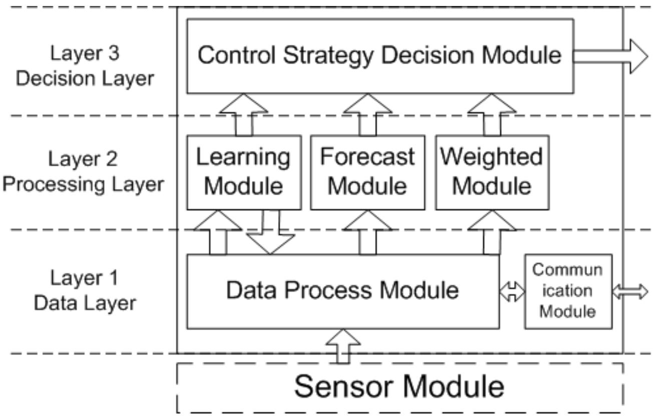

Fig.3 Components of Multi-agent system for traffic signal control framework

In the next layer, Processing Layer, deals with the factors that might impact control strategy of traffic signal. Traffic signal control strategy should take 3 factors into consideration, first, knowledge about past traffic flow data. Second of all, prediction on upcoming vehicles amount in this very intersection. Finally, importance (judge by traffic flow) of each different intersection should be considered.

Forecast Module is designed for the purpose of forecast possible traffic flow in a particular intersection. As shown in figure 4, we believed that traffic flow of intersection A is influenced by vehicles passing through nearby intersections. The influence of nearby intersections to intersection A is in proportion to the distance between these intersections. In other words, the far the two intersections are, the less the influence is.

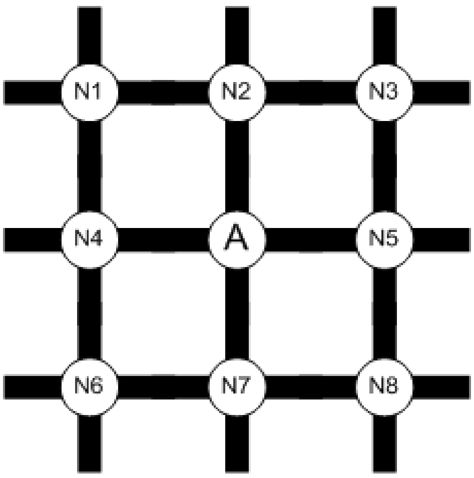

Fig 4 part of the traffic network

The predicted traffic flow of each intersection can be expressed as table 1. Take formula 2 for example, TotalUNx is the possible traffic flow to the north of intersection NX; UpNXNi stands for the possible influence to intersection NX by intersection Ni. UpNXNi is calculate by

$$UpNXNi = 1/distance * car\ queue \qquad (1)$$

Where car queue is the number of vehicle lining in front of the traffic light.

Table 1 Formula for predict possible traffic flow

TotalUNx=UpNxN1+UpNxN2…+UpNxNn $= \sum_{i=1}^{n} UpNxNi \qquad (2)$
TotalDNx=DownNxN1+DownNxN2… +DownNxNn= $\sum_{i=1}^{n} DownNxNi \qquad (3)$
TotalRNx=RightNxN1+RightNxN2… +RightNxNn = $\sum_{i=1}^{n} RightNxNi \qquad (4)$
TotalLNx=LeftNxN1+LeftNxN2…+LeftNxNn $= \sum_{i=1}^{n} LeftNxNi \qquad (5)$

Learning Module is used to achieve adaptation in our framework. There exist 2 learning strategies：

1. Short-term Learning：Consider only traffic flow and waiting car’ s queue in recent period of time, determined how it would affect traffic light control strategy.
2. Long-term Learning：Long-term learning aimed at discovers pattern or trend hidden in large amount of historical data (data from previous time).

Weight is given to different intersections with appropriate measurement according to the traffic flow rate of each intersection. Weighted Module in layer 2 is used to store the weighting result.

Decision Layer, consists Control Strategy Decision Module. Control Strategy Decision Module summarizes indices output from Learning Module, Weighted Module, Forecast Module and alter traffic light control strategy through modify cycle, split, offset of traffic light controller.

IV. EXPERIMENT AND PERFORMANCE EVALUATION

Experiment was aimed at determining the simulated total delay time of specific urban traffic network achieved by proposed decentralized ACTAM framework, when compare to conventional fix sequence traffic signal control strategy. In our experiment, the objective of control strategy is to minimize the total delay time. In our definition, total delay time is the sum of all cars’ waiting time in front of all traffic lights in specific traffic network. Total delay time for certain period of time is given by:

$$T = \sum_{i \in NET} \sum_{j=1}^{n} W_{ij} \qquad (6)$$

Where T is the total delay time, NET represents each car's summarized waiting time in front of all possible encounter traffic lights within the traffic network, n indicates number of vehicles in the network and Wij is waiting time in front of each traffic light.

The parameter settings used in our simulation are shown as follow:

- The traffic network used in our simulation contained 30 intersections, arranged as a 6*5 matrix.
- The distance between every intersection is the same (500m).
- Vehicle speed is set to 50 kilometers per hour
- Simulation time is set to 2 hours

The simulation is done with an Intel Pentium 4 PC.For fix sequence traffic signal control strategy, cycle and split of traffic light is predefined. In our simulation, cycle is set to 100 seconds per cycle, split for horizontal and vertical is set to 1:1. As for ACTAM, Control Strategy Decision Module is in charge of altering cycle and split to reduce total delay time. Cycle time of traffic light should increase when the traffic flow is getting crowned. Split should be set in proportion to the ratio of vertical and horizontal traffic flow. Tables below show how cycle and split is decide.

Table 2 Cycle for traffic light in this study

Type	Traffic condition	Cycle time
C1	R <1/45	40 seconds
C2	1/45< R <1/40	60 seconds
C3	1/40< R <1/35	80 seconds
C4	1/35< R <1/25	100 seconds
C5	1/25< R <1/20	120 seconds
C6	1/20< R <1/15	140 seconds
C7	1/15< R	160 seconds

Table 3 Split for traffic light in this study

Split-Vertical	Cycle * (D1/(D1+D2))
Split-Horizontal	Cycle * (D2/(D1+D2))

Where D1, D2 indicate vertical and horizontal traffic flow respectively, split is limited to 8:2 to 2:8.

Figure 5 and 6 show the comparisons between fix sequence traffic signal control strategy and ACTAM. As we can see from the diagram, ACTAM outperform the fix sequence traffic signal control strategy by 35%.

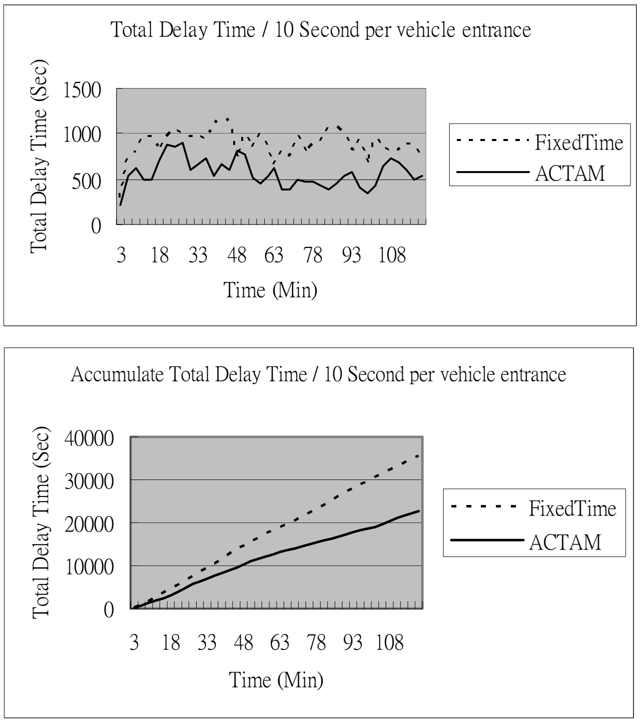

Fig. 5 Comparison of fix sequence traffic signal control strategy and ACTAM framework under condition of 10 seconds per vehicle enters the traffic network (a) Total Delay Time in 3 minutes time interval (b) Accumulate Total Delay Time
X axis: Time elapse Y axis: Total delay time

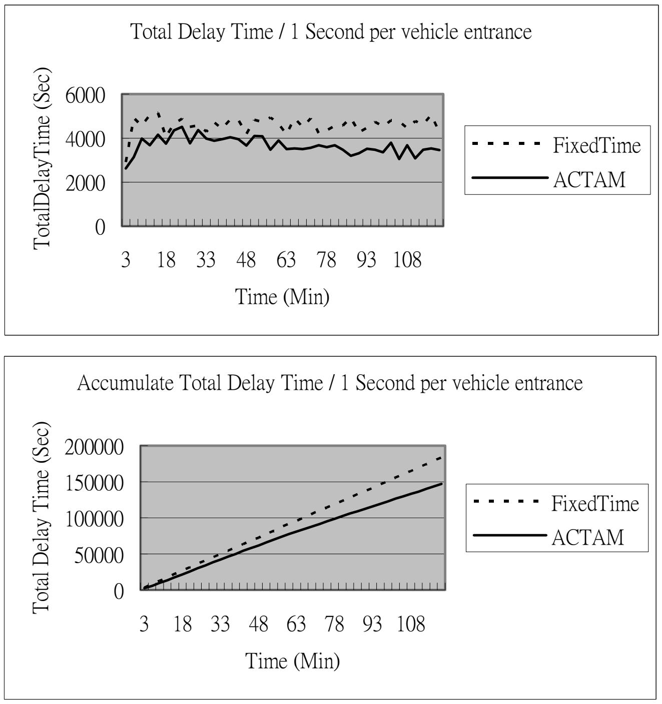

Fig. 6 Comparison of fix sequence traffic signal control strategy and ACTAM framework under condition of 1 seconds per vehicle enters the traffic network (a) Total Delay Time in 3 minutes time interval (b) Accumulate Total Delay Time
X axis: Time elapse Y axis: Total delay time

V. CONCLUSIONS AND FUTURE WORKS

Traffic congestion problem in urban area is a serious problem. The proposed ACTAM framework utilizes multi-agent systems for decentralized traffic signal control. Sensor Module in proposed framework is in charge of collecting traffic data; data layer in IIA receives data and exchanges data with other IIA in the network. Processing layer is used to generate indices represent factors that might affect control strategy for decision layer. Decision layer come up with control strategy based on the indices provided by processing layer and alter cycle, split, offset for a traffic light. In our simulation, we implemented Forecast Module, by predicting possible upcoming traffic flow; the regulator (traffic light) can follow the decision made by IIA and reduce total delay time. Our simulation result indicates that ACTAM out performed conventional fix sequence traffic signal control strategy by approximately 35%. ACTAM aimed at minimize total delay time in specific traffic network with decentralized control strategy decision-making. With decentralized control strategy, we gain on scalability since each IIA is in charge local optimization problem and no master controller is needed, thus, adding new intersections to the network increases only the computation loading on neighborhood intersections while rest of the network remain the same. Also, with decentralized control strategy, controller may be able to react to incident with short response time and in a proactive way. Since our objective is to minimize total delay time, IIAs' communication ability avoids them to pursue local optimization and therefore, achieve the goal of minimizing total delay time.

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