Dynamic Signal Timing for Eco-driving

Ho-jin Jung, Haeng-ju Lee, Sang-Hyuk Son
Information & Communication Engineering
DGIST
Daegu, republic of Korea
{hojinwkd, haengjulee, son} @ dgist.ac.kr

***Abstract*— Carbon dioxide (CO2) is a major greenhouse gas (GHG) and comes from power utilities, industry, and transportation. Among them, transportation alone account for about 16% of man-made CO2 emissions. More CO2 in transportation is emitted as stop-and-go movements of cars and traffic congestion. The previous eco-driving methods to control the stop-and-go movements have a major disadvantage of high computation time, and they obtain sub-optimum solutions because they only consider the leader car not the whole cars. The previous signal control methods to reduce traffic congestion also have the same disadvantage of high computation time. Furthermore, it is hard to incorporate eco-driving under the dynamic signal timing. In this paper, we propose dynamic signal timing for eco-driving (DSTED) with dynamic group eco-driving model and dynamic signal timing using a decision tree. The decision tree based on dynamic group eco-driving shows all possible cases of signal timing according to priorities of vehicles. The proposed system makes groups of vehicles according to inter-arrival times at the intersection in order to reduce the size of decision tree (i.e., to reduce the computation time). We apply A* algorithm to find a minimum-cost path in the decision tree, which is used to modify signal timing in real time. DSTED is realistic and practical by reducing the computation time of signal control and eco-driving using simple model. Also, it is possible to cope with real-time events immediately. Therefore, DSTED solves an eco-driving problem efficiently under dynamic signal timing (not merely under pre-defined signal timing).**

Keywords*— *dynamic signal timing, dynamic eco-driving, eco-sginal operations, CO2, and greenhouse gas.

I. INTRODUCTION

The Intelligent transportation system (ITS) exploits transportation engineering, computer software and hardware, and wireless communication to improve the efficiency of transportation system and has been an active research area for the last decade due to vehicular ad hoc network (VANET). The ITS brought new approaches in the transportation research area under the presence of vehicle-to-vehicle (V2V) or vehicle-to-infrastructure (V2I) communications. It solves problems of location prediction, and flow prediction using detectors. One of main objectives of the ITS is to reduce Carbon dioxide (CO2) emission, a major cause of global warming, and fuel consumption. Transportation alone accounts for about 16% of man-made CO2 emission [1]. The emission rate in traffic congestion is 1.6 times higher than that in free-flow. The emission rate is even higher when cars frequently decelerate and accelerate with stop-and-go movements. We should decrease idling situation, stop-and-go situation, and traffic congestion to reduce emission and fuel consumption in transportation system. The idling situation occurs when a car wait at a red light with no other cars around. Stop-and-go movements result from deceleration and acceleration by leader car or red signal.

To reduce fuel consumption and CO2 emission, there have been researches on eco-driving to control vehicles by recommending eco-speeds and researches on signal control by controlling the traffic signal timing. The goal of eco-driving research is to find optimal vehicle movements with lowest fuel consumption by decreasing stop-and-go movements. Some of them are impractical due to high computation time by simulating various values for deceleration, acceleration, and speed. To overcome the computational difficulty, some of them only consider a leader car rather than the whole cars. To reduce traffic congestion at an intersection, the researchers on traffic signal control change signal timing according to transportation situation. Some of them are impractical due to computational complexity to find to find optimal signal timing, whereas others extremely simplify the traffic condition by considering several vehicles as one vehicle.

The researches on eco-driving and those on signal control have been developed independently. The researches on eco-driving derive eco-driving solutions under pre-defined signal timing, not under dynamic signal timing because it causes non-smooth movements of vehicles. On the other hand, the researches on signal control find optimal solutions under the normal driving model, not under eco-driving model. In this paper, we propose dynamic signal timing for eco-driving (DSTED) with dynamic group eco-driving model and dynamic signal timing using a decision tree. The decision tree represents all cases of the order of vehicle arrivals. DSTED finds a leaf node of the decision tree with the minimum weight to find optimal signal timing. We use two methods to reduce computation time: grouping, and a tree search algorithm. For grouping, we use arrival times of vehicles at the intersection, not just headways. For a tree search algorithm, we use A* search algorithm.

The remainder of this paper is organized as follows: in Section 2 we overview of related work in the field of traffic signal assistance systems as well as driving strategies. In Section 3 we introduce dynamic signal timing for eco-driving algorithm, and a process of DSTED. The setup and details of our simulations will be presented in Section 4.

II. Related Works

The researches on eco-driving are divided into three parts: eco-driving using signal timing, eco-driving using signal timing and information of other vehicles, and dynamic eco-driving. Eco-driving using signal timing finds an optimal movement of one vehicle with the minimum emissions or the minimum fuel consumption using remaining green time and remaining red time of traffic signal [2, 3, 4]. Eco-driving using signal timing and information of other vehicles utilizes speed of leader vehicle as maximum speed because it can't overtake the leader vehicle in the same lane [5, 6, 7, 8]. Dynamic eco-driving is practical due to the low computation time, but it does not consider the whole cars [9, 10, 11].

The signal control researches can be categorized into four groups: fixed-time traffic signal control, responsive traffic signal control, adaptive traffic signal control, and real-time adaptive traffic signal control [12]. Fixed-time traffic signal control is that signal timing is fixed even though the traffic volumes are changing. Hence, it is not suitable for a dynamic road condition. Responsive traffic signal control uses detectors to know the existence of a vehicle. If there are a lot of cars in one phase, it can extend green time of the phase using detectors. Adaptive traffic signal control uses information from detectors or VANET to know locations and speeds of vehicles. We can obtain adaptive signal timing by predicting the next traffic condition using the information. Real-time adaptive traffic signal control is practical because of low computation time, but it is not suitable for eco-driving under the dynamic signal timing [13].

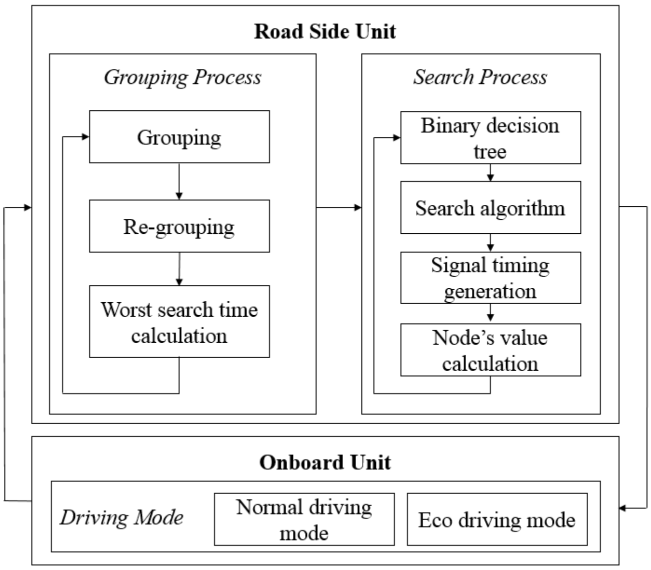

Fig. 1. Dynamic signal timing for eco-driving

III. DYNAMIC SIGNAL TIMING FOR ECO-DRIVING ALGORITHM

This algorithm finds dynamic signal timing for eco-driving, which means eco-driving is performed under dynamic signal timing. In other words, the algorithm considers signal timing model and eco-driving model at the same time. First of all, we should find the signal timing for eco-driving. The methods to find signal timing are widely classified into two parts: optimization using signal timing, and signal timing using priorities of vehicles. The former is optimization to find the minimum value of objective function using possible sets of signal timings. The latter finds signal timing by calculating occupancy time at the intersection according to priorities of vehicles. We adopt the latter one because it does not have a standardized search method (i.e., genetic algorithm of the former one). It finds an optimal solution once we know traffic patterns according to situation. Our system has road side unit (RSU) at the intersection and on-board units (OBU) in the vehicles. If OBUs send information to RSU such as location, speed, and desired speed, RSU finds optimal signal timing using the information and change the traffic signal according to the signal timing. If RSU sends the optimal signal timing to OBUs, drivers follow eco-driving using the optimal signal timing. This DSTED algorithm is composed of two parts: grouping process, and search process. The first one makes groups of vehicles to deal with computation time and complexity. The second one finds the leaf node with the minimum value of node using a search algorithm.

A. *Grouping Process*

A general grouping method uses particular headway but this algorithm uses inter-vehicle arrival time (IVAT) at the intersection when all traffic signals are green. IVAT means the difference of arrival times at the intersection between vehicles. Optimal signal timing means that IVAT at the intersection is same with minimum headway. Even though headway between vehicle 'A' behind a leader vehicle and the leader vehicle is larger than minimum headway, the headway between the 'A' and the leader can minimum headway at the intersection if the speed of the 'A' is larger than the speed of the leader. Therefore, we should use IVAT instead of headway for signal timing.

All groups generated by IVAT or headway can affect other groups. It needs re-grouping to consider effects between groups with different phases. Re-grouping is done when a group with phase 'P1' to arrive at the intersection conflicts with other groups with phase 'P2' to arrive at the intersection in a situation that all traffic signals are green. Target of re-grouping is the group to arrive first at the intersection among the conflict groups. It means that speed of a group who arrives at last can increase through re-grouping of a group who arrives first.

Worst search time is calculated using the number of groups generated by re-grouping. This calculation formula changes with search algorithm. If the worst search time is larger than the maximum search time, this algorithm increases IVAT to reduce search time. If the IVAT increases, search time will decrease by reducing the number of groups but it can be away from optimal solution. If the IVAT decrease, search time will increase inversely. The most suitable case has maximum number of groups within maximum search time. The groups in the most suitable case are chosen for search process.

B. *Search Process*

A decision tree are created using groups generated by the grouping process explained before. Search process finds a leaf node of the decision tree with the minimum value using a search algorithm. We adopt A* search algorithm to find a least-cost path from a given initial node to one goal node.

If it arrives at a leaf node as a goal node using A* search algorithm, we can obtain the order of vehicle arrivals because search process to find the leaf node is the order of vehicles. We can obtain signal timing using occupancy times at the intersection according to the order of vehicles. We can obtain a value of node using prediction model that has characteristic of driving model such as normal driving, and eco-driving.

IV. SIMULATION SETUP

For simulation experiments, we use a traffic simulator using MATLAB program. Three different traffic conditions are considered: low traffic volumes, middle traffic volumes and high traffic volumes to compare various signal control. The road network consist of two lanes with one-way traffic. For each traffic condition, the simulation runs ten times with different random seed. We consider the following performance measures: cumulative travel time, cumulative delay time, and fuel consumption. All vehicles follow Newell's model that is a simple and reasonable car-following model. The fuel consumption will be calculated from VT-micro calculator using the vehicle trajectories of 200 meters before the intersection and 100 meter after the intersection. All cars have dedicated short range communication-based (DSRC) on board unit (OBU) and there is a controller to control signal timing at the intersection. We assume that the controller at the intersection can recognize the whole cars within 200 m, and there is no communication delay. We will compare performances of pre-timed signal control, actuated signal control, real-time adaptive signal control, and dynamic eco-driving.

V. CONCLUSION AND FUTURE WORKS

The main contribution of the paper lies in the integration of signal control with eco-driving. Under the normal riving, the reduction rates of the proposed algorithm over the pre-timed method in cumulative travel time, cumulative delay, and fuel consumption are 53%, 70%, 30% respectively in low traffic volumes, and 8%, 6%, 9% respectively in high traffic volumes. Under eco-driving, we expect to have more reduction rates than those under normal-driving.

ACKNOWLEDGMENT

This research was supported in part by Global Research Laboratory Program (2013K1A1A2A02078326) through NRF, and the DGIST Research and Development Program (CPS Global Center) funded by the Ministry of Science, ICT & Future Planning.

REFERENCES

[1] http://www.oica.net/category/climate-change-and-co2/

[2] Eckhoff, David, Bastian Halmos, and Reinhard German. "Potentials and limitations of Green Light Optimal Speed Advisory systems." VNC. 2013.

[3] Staubach, Maria, et al. "Evaluation of an eco-driving support system."Transportation research part F: traffic psychology and behaviour 27 (2014): 11-21.

[4] Rakha, Hesham, and Raj Kishore Kamalanathsharma. "Eco-driving at signalized intersections using V2I communication." Intelligent Transportation Systems (ITSC), 2011 14th International IEEE Conference on. IEEE, 2011.

[5] Niu, Dening, and Jian Sun. "Eco-driving Versus Green Wave Speed Guidance for Signalized Highway Traffic: A Multi-vehicle Driving Simulator Study."Procedia-Social and Behavioral Sciences 96 (2013): 1079-1090.

[6] Mensing, Felicitas, et al. "Eco-driving: An economic or ecologic driving style?."Transportation Research Part C: Emerging Technologies 38 (2014): 110-121.

[7] Suzdaleva, Evgenia, and Ivan Nagy. "Data-based speed-limit-respecting eco-driving system." Transportation Research Part C: Emerging Technologies 44 (2014): 253-264.

[8] Yang, Hao, and Wen-Long Jin. "A control theoretic formulation of green driving strategies based on inter-vehicle communications." Transportation Research Part C: Emerging Technologies 41 (2014): 48-60.

[9] Alsabaan, Maazen, Kshirasagar Naik, and Tarek Khalifa. "Optimization of fuel cost and emissions using v2v communications." Intelligent Transportation Systems, IEEE Transactions on 14.3 (2013): 1449-1461.

[10] Xia, Haitao, Kanok Boriboonsomsin, and Matthew Barth. "Dynamic eco-driving for signalized arterial corridors and its indirect network-wide energy/emissions benefits." Journal of Intelligent Transportation Systems 17.1 (2013): 31-41.

[11] Barth, Matthew, et al. "Dynamic ECO-driving for arterial corridors." Integrated and Sustainable Transportation System (FISTS), 2011 IEEE Forum on. IEEE, 2011.

[12] Li, Li, Ding Wen, and Danya Yao. "A survey of traffic control with vehicular communications." Intelligent Transportation Systems, IEEE Transactions on15.1 (2014): 425-432.

[13] Xie, Xiao-Feng, et al. "Platoon-based self-scheduling for real-time traffic signal control." Intelligent Transportation Systems (ITSC), 2011 14th International IEEE Conference on. IEEE, 2011.