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A study on traffic signal control at signalized intersections in vehicular ad hoc networks

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ABSTRACT

The Seoul metropolitan government has been operating a traffic signal control system with the name of COSMOS (Cycle, Offset, Split MOdel for Seoul) since 2001. COSMOS analyzes the degrees of saturation and congestion which are calculated by installing loop detectors. At present, subterranean inductive loop detectors are generally used for detecting vehicles but their maintenance is inconvenient and costly. In addition, the estimated queue length might be influenced by errors in measuring speed, because the detectors only consider the speed of passing vehicles. Instead, we proposed a traffic signal control algorithm which enables smooth traffic flow at intersections. The proposed algorithm assigns vehicles to the group of each lane and calculates traffic volume and congestion degree using the traffic information of each group through inter-vehicle communication in Vehicular Ad-hoc Networks (VANETs). This does not require the installation of additional devices such as cameras, sensors or image processing units. In this paper, the algorithm we suggest is verified for AJWT (Average Junction Waiting Time) and TQL (Total Queue Length) under a single intersection model based on the GLD (Green Light District) simulator. The results are better than random control method and best-first control method. For a generalization of the real-time control method with VANETs, this research suggests that the technology of traffic control in signalized intersections using wireless communication will be highly useful.

1. Introduction

Nowadays, many countries are struggling with severe daily traffic congestion that causes a huge amount of social and economic loss. According to the report of Improvement of the Estimation Method for Traffic Congestion Costs from The Korean Transport Institute, the economic loss due to traffic congestion in 2007 is estimated to be approximately $14.4 trillion [1]. Additional waste of time and energy are also a significant loss for individuals and nations.

To resolve such traffic congestion, traffic signal control methods are applied to improve traffic flow at intersections. The control methods can be largely classified into time-of-day (TOD), fixed-time control and real-time control methods. The time-of-day control method follows a predefined signal timing plan by hour/day. The fixed-time control method uses a signal timing plan set by an administrator, while real-time control analyzes traffic information acquired by sensors and builds a proper signal timing control [2].

Time-of-day and fixed-time control methods have advantages in the sense that they do not require additional hardware and nor a complicated control algorithm. However, traffic congestion in modern urban areas is caused not only by periodical rush-hours but also occasional events interfering with the traffic flow, such as traffic accidents and road construction. In addition, speed bumps, curved roads and vehicle speed instability due to careless drivers can also cause traffic congestion. Therefore, time-of-day and fixed-time control methods can possibly even increase traffic congestion instead [3].

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Nomenclature

RQL	queue length in the present cycle length	*MAX_Q*	maximum queue length
QL	final queue length for real-time signal control	*R_CL*	temporal required cycle length
D	identifier which is combined with path and incoming direction	N_{MAX_Q}	number of vehicles in the maximum queue length
VL	vehicle length	*h*	vehicle-to-vehicle headway
ADBV	average distance between vehicles	*GT*	green time
N	number of group memebers	GT_T	total green time
l	length of lane	*R_GT*	required green time
CL	cycle length	*V*/*C*	flow ratio

On the contrary, the real-time control method is based on real-time sensing which potentially makes it an appropriate strategy to resolve traffic congestion in modern urban cities. Moreover, recent improvement in converged technologies of sensing and wireless networks has enabled the development of various real-time control methods.

Attaining information of accurate vehicle detection is the most important factor for real-time signal control. The most widely used sensors for vehicle detection at present are spot traffic detectors and regional traffic detectors. Spot traffic detectors such as loop detectors and ultrasonic detectors are sensors buried under the road, which makes their maintenance inconvenient and costly. Other types are microwave detectors and image detectors, which are easy to install but also have high maintenance cost. The types of regional traffic detectors are AVI (Automatic Vehicle Identification), beacon and GPS (Global Positioning System) probe. Regional traffic detectors are generally high priced and occasionally show low accuracy with regards to road conditions. In addition, both spot traffic detectors and regional traffic detectors are only able to cover a limited local area, and cannot used for route prediction [4].

In this study, a method of queue length estimation using communication between vehicles in a Vehicular Ad-hoc Networks (VANETs) environment is proposed. This method does not require the installation of additional detectors and allows the estimation of optimal cycle length and green split to enable real-time control of signalized intersections.

The remainder of the paper is organized as follows.

- Traffic control system using VANETs (Section 3.1).
- Intersection model and phase configuration. (Section 3.2)
- Queue length estimation algorithm using VANETs (Section 3.3).
- Cycle length and green split estimation. (Section 3.4).
- Simulation environment (Section 4).
- Simulation results (Section 5).
- Conclusions (Section 6).

2. Related works

In this chapter, research on vehicle queue length estimation and signal control system is described. Vehicle queue length is defined as the number of vehicles that cannot pass the intersection within red time and can be used to determine whether green time needs to be extended. It also allows controllers to clear the queue at the intersection in order to improve traffic flow.

The Seoul metropolitan government has been operating a traffic signal control system with the name of COSMOS (Cycle, Offset, Split Model for Seoul) since 2001. COSMOS analyzes the degrees of saturation and congestion which are calculated by installing loop detectors such as forward detectors, left-turn detectors, spillback detectors and queue length detectors. Traffic control using queue length is one of the most optimal real-time control methods. Its disadvantage is that it requires detectors to be installed in each lane since it relies on the data from both the upstream queue length detector and the downstream spillback detector. In addition, the estimated queue length might be influenced by errors in measuring speed, because the detectors only consider the speed of passing vehicles. To overcome such limitations, research with various sensors has been conducted. Some of the research proposed a method of obtaining local vehicle information using RFID tags attached to vehicles and RFID readers installed in each lane [5].

Malik et al. [6] proposed a method to obtain traffic information by installing sensor nodes in each lane and controllers in each lane within a sensor network environment. Also, Khalil et al. [7] proposed a method to aggregate vehicle information by installing pairs of arrival and departure nodes with one traffic signal server at intersections. Park et al. [8] proposed a queue length estimation model that uses occupancy time to minimize errors caused by the dependence on the average vehicle length and Instantaneous speed of the estimation process.

Jeong et al. [9] proposed a method that estimates dequeuing time by measuring the delay time of individual vehicles before calculating the saturation flow ratio with the estimated de-queuing time. The estimated saturation flow ratio is used to calculate the queue length of each lane and the final queue length is obtained after compensating for errors. Lee and Oh [10] proposed a queue length estimation algorithm using a pair of image detectors installed at upstream and downstream lanes.

This study proposes a real-time queue length estimation algorithm that generates vehicle groups in each lane by using traffic signal cycle length and calculates the queue length using inter-vehicle communication within a