ADAPTIVE VIRTUAL TRAFFIC LIGHT BASED ON VANETS FOR MITIGATING CONGESTION IN SMART CITY

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ABSTRACT

Fixed cycle traffic lights decrease the throughput of traffic at intersections. Adaptive traffic light approaches dynamically change the cycle of traffic lights according to current traffic, these approaches usually improves traffic. However, it costs many resources to maintain all physical traffic lights in a city, and conventional adaptive traffic light approaches were designed for physical traffic light systems, rather than virtual traffic light (VTL). VTL approaches will be a feasible solution to facilitate energy efficiency in a smart city; therefore, this paper proposes a VTL approach based on vehicular ad-hoc networks (VANETs) in smart city. The proposed approach adapts the cycle of VTL according to current traffic and vehicle type via VANETs. The results show that the proposed approach improves average speed by 10.1%, when compared with fixed cycle traffic lights.

KEYWORDS

VANETs, virtual traffic light, smart city, transportation, ICT

1 INTRODUCTION

World is urbanizing, nowadays, half of the world’s population lives in transportation convenient cities. Urbanization facilitates economics growth and technique progress, but causes environmental pollutions and energy consumptions. Therefore, environment protection and energy-efficiency improvement are important issues in a smart city [1]. Governments or enterprises are encouraged to integrate information and communication technology (ICT) into city management, for example Cisco co. supports the development of Busan city in Korea [2]. Its researches cover many topics: healthcare, energy and water, environment pollution, resource recycling, transportation, entertainment, government services, public safety, education, and ICT systems [3].

By 2050, Ford Motor forecasts the number of global vehicles to increase to 4 billion due to growth in the current population. Generally the commute time of population in U.S. accounts for 25.2 minutes of a day [4], even in holidays or festivals, human migration brings a very heavy traffic and global warning problems in many cities. To solve the problem, governments deploy a lot of sensors in a smart city. The sensors monitor pedestrians, vehicles, infrastructures and environment. Each object in a smart city is connected to form an ICT-based transportation network. Over the past decade, ICT was also applied to vehicular ad-hoc networks (VANETs) in transportation systems. VANETs communication architecture can be divided into the Vehicle to Vehicle communication (V2V) and Vehicle to Infrastructure communication (V2I) [5], as shown in Figure 1 The cities get transportation information and control traffic lights to guide vehicles and pedestrians. The purpose of first generation traffic light is to protect pedestrians from carriages; nowadays, traffic lights control the traffic flow of cities. In U.S., the installation cost of a traffic light is more 50 thousand dollars, and its electric bill is 3 thousand dollars per year. The expenditure of 50 million intersections is heavy.

Figure 1. VANETs environment
Since 62.75% intersection accidents occur in intersections without traffic light, vehicles organize a virtual traffic light (VTL) via VANETs to improve safety in intersections that without physical traffic lights [7]. VTL controls vehicles when they approach an intersection. To improve the throughput of traffic at an intersection, VTL dynamically adapts its cycle according to current traffic information, so called adaptive VTLs. Moreover, adaptive VTLs can shorten commuting time, reduce carbon emissions, and improve energy consumptions in a smart city.

An urban system often has traffic congestions because of the frequent stop-and-wait of vehicles. Therefore, this paper proposes an Adaptive Virtual Traffic Light (AVTL) based on VANETs. The contributions of this work are as following:

1. The proposed AVTL approach controls VTL for intersections to mitigate the congestion.
2. The proposed AVTL approach dynamically adapts the cycle of traffic lights according to three vehicle types, such as light vehicles, buses, and emergency vehicles.

The results show that the proposed AVTL approach improves average speed by 10.1%, when compared with fixed cycle traffic lights. This article is organized as follows. Section II describes related works. Section III describes the proposed AVTL architecture. Then, simulation results are given in Section IV. Final is the conclusion.

2 RELATED WORKS

To improve traffic flow at an intersection, Road-Side Unit (RSU) is used for controlling traffic lights. Via V2I communication, vehicles send a message to RSU when they approach an intersection. RSU calculates current traffic flows and average speed according to the received messages to control its traffic lights, such as green time extending [8]. If an intersection is without traffic lights, RSU also can send vehicles a virtual traffic signal to avoid collisions. The traffic signal contains green/red time, intersection identity and generating time. Virtual traffic light approach is proposed for cutting down the maintain cost of each traffic light and RSU at intersections. Virtual traffic lights also can reduce CO2 emissions [7]. Vehicles exchange messages, including vehicle type, instant speed, moving direction and timestamp, via V2V communication. Only one vehicle is selected as vehicle header at an intersection. Vehicle header calculates a traffic light cycle according to current traffic information, and broadcast its traffic signal to other non-header vehicles. A traffic light cycle contains green time and red time. Drivers may confront a novel user interface system, such as human machine interface, to display virtual traffic lights [9].

3 PROPOSED AVTL

In this paper, the proposed AVTL is based on VANETs in a city environment. Even if an intersection is without building any physical traffic lights on it, vehicles still can efficiently cross the intersection. Besides, the proposed approach also can mitigate collisions at an intersection. Firstly, this paper assumes that each vehicle is equipped with an on-board unit (OBU) whose models contain a global position system, a wireless communication facility, and e-maps. Vehicles can exchange information with each other via OBU, and OBU provides high security communication channels without any disconnection. Drivers should obey with the traffic signals of the proposed approach, in this paper. The routing protocol supports carry and forward technique.

The architecture of proposed AVTL contains three functions: planning, management and operating functions, so called smart cycle function. In planning function, vehicles collect beacon messages from their neighboring vehicles for the selection of leader candidates. The beacon messages contain instant speed, location, travel time, next-intersection, moving direction, vehicle identity, vehicle type and generating time. Vehicles also can control their beacon frequency to avoid broadcast storm. In management function, the selected leader creates and maintains its own AVTL, each intersection only has one leader. In operating function, vehicles receive traffic signals broadcasted by the selected leader. The traffic signals are shown on the screen of OBU. The data flow among these three functions is shown in Figure 2. It contains three kinds of message: beacon, lane, and VTL messages.

![Figure 2. Data flow of the proposed AVTL](image-url)
3.1 Planning Function

Each vehicle periodically calculates a travel time from its current position to its next-intersection, and broadcasts beacon messages that contain the calculated travel time. When vehicles receive a beacon message, this function updates its neighbor table. Via the exchange of beacon messages, one vehicle that has the shortest travel time is selected as a leader candidate, if there is not any leader candidate on a road segment. A road segment represents a street between two intersections. Then, the selected leader candidate broadcasts lane messages to other vehicles and other leader candidates. The lane messages contain vehicle identity, travel time, next-intersection, road segment identity, average speed of neighbors, number of neighbors and generating time. In this paper, each road segment only has one leader candidate. For example, if an intersection has 3 adjacent road segments, its maximum number of leader candidates is 3, and so on.

3.2 Management Function

Each intersection only one leader candidate can be selected as a leader when the leader candidates approach an intersection. The street system is composed of branch roads and main roads, most branch roads have sparse vehicle density. In this paper, there are three vehicle types: light vehicle $l$, bus $m$, and emergency vehicle $e$. If all leader candidates are on branch roads or main roads, each leader candidate has to calculate a weight $w_{all}$ according to its rear vehicles as follows:

$$w_{all} = n_l \cdot w_l + n_m \cdot w_m + n_e \cdot w_e$$  \hspace{1cm} (1)$$

where $n$ represents vehicle number, $w$ is the weight of vehicle type, $w_l < w_m < w_e$. Then, a leader candidate that has the smallest weight $w_{all}$ is selected as leader. If the selected leader has not enough safe stopping distance, a leader candidate that has the second smallest weight $w_{all}$ is selected as leader, and so on.

In this paper, the selected leader has to wait and controls its AVTL. Therefore, traffic signal of leader is set as red/stop. For example, in Figure 3 there are two leader candidates, A and B, on vertical and horizontal road segment separately. Moreover, there are two light vehicles and one bus on a horizontal road segment, and three light vehicles on a vertical road segment. The weight of vehicles $w_{all, A}$ on horizontal road segment is larger than the weight of vehicles $w_{all, B}$ on vertical road segment. Therefore, leader candidate A is selected as leader, and A’s traffic signal is set as red. Leader candidate B will receive a green/go signal from leader A. Leader candidate B also broadcasts the green signal to its rear vehicles.

If the part of leader candidates are on main roads and other part of leader candidate are on branch roads, one leader candidate on branch roads is selected as leader. If there are more than one leader candidates on branch roads, one has the shortest travel time is selected as a leader. Vehicles on branch roads have to wait; therefore, traffic signals of branch roads are set as red. The selected leader has to broadcast VTL messages to other vehicles that are in the transmission range $r$. The VTL messages contain VTL type, intersection identity, traffic signal, cycle time and generating time. Furthermore, the selected leader on branch road has to synchronize its AVTL with other leader on adjacent intersections.

The selected leader calculates the cycle of traffic light according to the number of vehicles on main roads. The leader finds the maximum number of neighbors $n_q$ from the received lane messages that are broadcasted by the candidate leader on main roads. The green cycle $t_g$ is as follows:

$$t_g = \min\left\{ \frac{n_q \cdot t_{max}}{\rho}, t_{max} \right\}$$  \hspace{1cm} (2)$$

where $t_{max}$ is the maximum green cycle, $\rho$ represents the throughput of road segment in unit of vehicles/sec.

3.3 Operating Function

When vehicles are waiting or stopping, this function checks whether the current position is destination or not. If not, vehicles countdown the traffic cycle after they receive a VTL message broadcasted from leader. The traffic signal is
shown on the screen of OBU, driver can comply with the signal to go through multiple intersections. If vehicles do not receive any VTL messages, vehicles can go through intersections and periodically send beacon messages.

### 4 SIMULATION RESULTS

This paper uses NCTUns 6.0 [10] as network simulator tool. NCTUns provides OBU and SignalAgent modules. OBU module can exchange information with each other. SignalAgent module can control traffic signal according to real time information. This paper creates a random travel of vehicle model by Random Waypoint Model [11].

In this paper, vehicles are composed of 97% light vehicles, 2% buses, and 1% emergency vehicles on the following simulations. Their speed limit, acceleration and deceleration settings are shown in Table I. There are four intersections (blue boxes) on main roads and eight intersections (white boxes) on branch roads in 1,000 meters × 1,500 meters simulation area, as shown in Figure 4. Simulation parameters are as follows: IEEE 802.11p is MAC protocol, and its transmission range is 250 meters. The transmission frequency of beacon message, lane message and VTL message is set as 100 milliseconds. The road length of each two-way road segment is 500 meters, and there are 4 lanes. In this paper, the number of vehicles is 200, 400, 600 and 800 respectively. In following results, \( w_l \) has low priority 1, \( w_m \) is medium priority 3, \( w_e \) has high priority 100, \( t_{\text{max}} \) is 120 seconds.

Figure 5 and Figure 6 show the impact of vehicle density on average speed for AVTL approach. Figure 5 shows the average speed of all vehicles. If the number of vehicles is 200, the proposed AVTL approach improves the average speed of all vehicles by 33.1% when compared with fixed cycle traffic light (FCTL) approach. If the number of vehicles is 800, the proposed AVTL approach improves the average speed of all vehicles by 10.1% when compared with FCTL approach. In addition, Figure 6 shows the average speed of emergency vehicles. If the number of vehicles is 800, the proposed AVTL approach improves the average speed of emergency vehicles by 62.06% when compared with FCTL approach. In this paper the average speed of emergency vehicles is faster than the average speed of light vehicles and bus, because the emergency vehicles have high priority to go through intersection without wait and stop.

### 5 CONCLUSIONS

The proposed AVTL approach can adapt the cycle of traffic lights according to vehicle types. Results show that the proposed AVTL approach effectively improves the throughput of intersections when compared with TL approach. If vehicle density is heavy, the proposed AVTL

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Vehicle Types</th>
<th>Max Speed (km/hr)</th>
<th>Max Acceleration</th>
<th>Max Deceleration</th>
</tr>
</thead>
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<tr>
<td></td>
<td>Light Vehicle</td>
<td>60 km/hr</td>
<td>1 m/s²</td>
<td>4 m/s²</td>
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<tr>
<td></td>
<td>Bus</td>
<td>50 km/hr</td>
<td>0.5 m/s²</td>
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<tr>
<td></td>
<td>Emergency Vehicle</td>
<td>100 km/hr</td>
<td>2 m/s²</td>
<td>5 m/s²</td>
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approach improves the average speed of emergency vehicles by 62.06% and the average speed of all vehicles by 10.1% when compared with FCTL approach.

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