A Lane-Level Dynamic Traffic Control System for Driving Efficiency Optimization Based on Vehicular Networks

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***Abstract*—In this paper, we propose a lane-level dynamic traffic control (LDTC) system targeting at driving efficiency optimization. The LDTC system integrates vehicular networks with intersection cameras to collect fine-grained information of vehicles, such as turning intentions and lane positions. LDTC can maximize the intersection throughput and provide fairness among traffic flows. With vehicular networks, the traffic controller of an intersection can collect all turning information before vehicles make their turns. With intersection cameras, the lane positions of vehicles can be detected even if GPS is not accurate enough to provide lane localization. In addition, the traffic condition can be continually monitored as some vehicles are not equipped with onboard units for vehicular communications. In LDTC, while allocating the green light to the traffic flows with higher passing rates for throughput maximization, it also allocates the green light to the ones with lower passing rates for fairness provision. This paper demonstrates our current prototype.**

Keywords: Dynamic Traffic Control, Image Recognition, Lane Localization, Traffic Light Timing, Vehicular Network.

I. Introduction

The rapid progress of connected vehicles has made Intelligent Traffic Control (ITC) possible at a micro or per vehicle basis to improve the driving efficiency. There is not only the need of intelligent control algorithms and platforms for ITC but also new practical technologies that can provide smooth transition from the contemporary. Insufficient penetration rate of onboard units (OBUs) is obstructing the utilization of vehicular communications for practical ITC. To solve this problem, we integrate vehicular networks with intersection cameras to provide both a smarter ITC system and a transition way where there is no 100% penetration of OBUs from the first deploying day.

Traditional traffic control systems rely on traffic information collection methods with roadside sensors external to vehicles (e.g., induction loops [1], magnetic sensors [2], etc). These are only able to provide limited information of vehicles, such as queue lengths. Thus, their traffic scheduling can not take vehicle mobilities into consideratio, which depend on vehicle types and lengths, driver acceleration habits, and turning intention (indicating the directions vehicles will turn when they pass the intersection).

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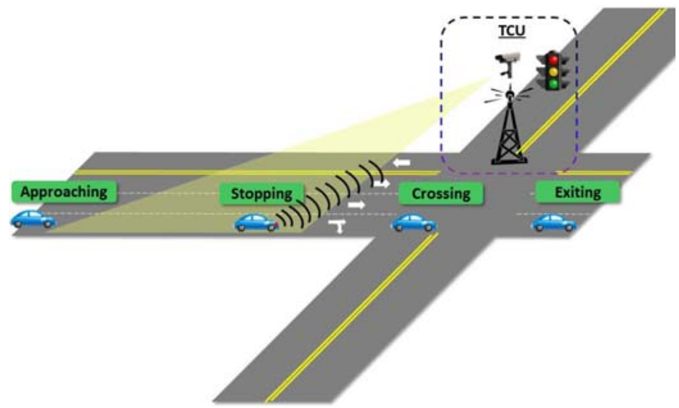

Fig. 1. System architecture of LDTC.

New approaches to collect traffic information involve wireless sensor networks (WSNs) [3], RFIDs [4], and vehicular networks (VNs) [5]. WSN-based systems rely on a lot of roadside sensors, while RFID-based systems require installation of a number of RFID readers, which both incur huge infrastructure cost. They require extensive infrastructure deployment and large amount of time for digging of roads. Furthermore, WSN-based and RFID-based systems are usually dedicated for traffic use only and have no other value addition. VN-based systems integrate an OBU with a GPS receiver in each vehicle, which are adopted in our system for dynamic traffic control. For the practicality, we integrate VNs with existing intersection cameras to overcome the penetration problem that not all vehicles are equipped with OBUs.

In this work, we propose a lane-level dynamic traffic control (LDTC) system using VNs and intersection cameras to utilize fine-grained information, such as lane positions and turning intentions of vehicles, for maximizing the intersection throughput and providing fairness among traffic flows. The turning intention of a vehicle is estimated from its turning indicator status, current located lane, and historical turning data. Using VNs, the traffic controller of an intersection can collect the turning information before vehicles make their turns.

On the other hand, with intersection cameras, the lane positions of vehicles can be detected as the GPS errors is not accurate enough to provide lane localization. In addition, the traffic information can be continually collected even if some vehicles are not equipped with onboard units for vehicular communications. The LDTC system takes the mixing of vehicles with different turning intentions into consideration. In particular, while allocating the green light to the traffic flows with the higher passing rates for throughput maximization, LDTC also allocates the green light to the ones with the lower passing rates for fairness provision.

II. System Design

Fig. 1 shows the system architecture and vehicle states at different locations nearby an intersection. On the intersection side, our system consists of a traffic control unit (TCU), which decides, controls and transmits the traffic light timing to vehicles at the intersection. The TCU consists of a roadside unit (RSU) and a microprocessor. In addition, it is interfaced to the intersection camera that is used to augment traffic information collected by the RSU at the intersection. On the vehicle side, a vehicle unit (VU) is set up inside a car to (i) collect/record the vehicle information, (ii) send the collected information to the TCU, and (iii) receive the traffic light timings back. The VU consists of an onboard unit (OBU), an On Board Diagnostics (OBD) interface [6], a GPS receiver, and a microprocessor controlling all those components. The OBU is to communicate with the RSU for vehicle registration/deregistration and the GPS receiver can calculate locations. The OBD interface is to capture the current vehicle status, such as vehicle's turning intention, speed, and acceleration. OBD can further help logging of driver acceleration patterns at intersections.

As a vehicle stops at an intersection due to red lights, it will register itself and transmit its vehicle information to the TCU, such as acceleration, de-acceleration, position, turning intention, and driver reaction time. As a registered vehicle passes the intersection, it will deregister itself to the TCU. Thus, the TCU can collect the traffic information of all vehicles waiting at the intersection and dynamically control its traffic signal based on the collected information.

A vehicle detects its approach to the intersection using the GPS and digital maps stored locally. Upon stopping at the intersection, the vehicle sends a registration message to the TCU. The registration message consists of parameters, such as current location, driver turning intention, vehicle type, velocity, driver acceleration, habits, etc. These enable the TCU to determine where the vehicle is at the intersection and what will be its mobility pattern when the traffic light turns green for the lane the vehicle is waiting on. Traffic control decisions are primarily aimed to provide maximum vehicle throughput at the intersection by giving the lane with maximum vehicle passing rate the right of way. After receiving the registration message, the TCU replies an acknowledgement message containing the traffic light timing and information about its lane location.

The TCU also employs an intersection camera to detect road condition at the intersection through image recognition. The recognition data is used to collect supplementary information of vehicles when there are not all vehicles equipped with VUs for vehicular communications. In addition, using an intersection camera can improve the location information provided by OBU and GPS, especially for the lane position of a vehicle that is a key parameter used in LDTC. Our system can successfully operate in both 100% and non-100% penetration of VUs on the road, and automatically transit between them by detecting those stopping vehicles without registrations through image recognition techniques.

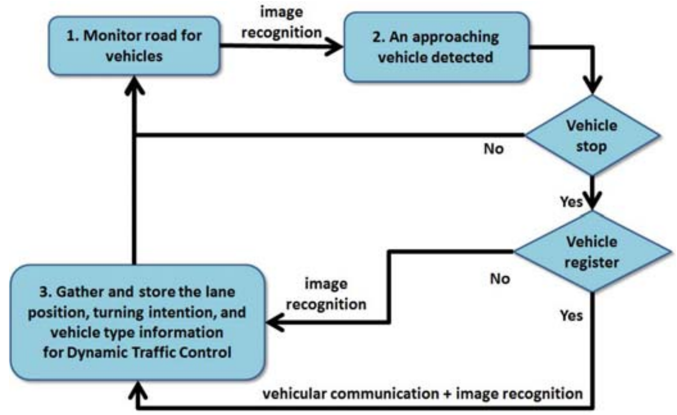

Fig. 2. Flowchart of LDTC operations.

Fig. 2 shows the flowchart of LDTC operations. Initially, LDTC monitors arriving vehicles on the road. When a vehicle approaches the intersection, it will be detected by the intersection camera. If the vehicle passes the intersection without stopping, LDTC will keep monitoring other arriving vehicles. Otherwise, the vehicle stopping at the intersection will register itself to the TCU through its VU. When the vehicle stops at the intersection more than once due to congested traffic flows, it will register itself to the TCU again. If the vehicle does not register itself to the TCU due to without an VU installed, its stopping still can be detected by the intersection camera. When the vehicle exits the intersection, it will deregisters itself from the TCU.

We consider an intersection with four road segments and each road segment has three different traffic flows, RIGHT-TURN, GO-STRAIGHT and LEFT-TURN. The attributes of the traffic flows are referred as *movements* that include *RIGHT_ONLY*, *STRAIGHT_RIGHT*, *LEFT_ONLY*, and *ALL_THROUGH*. The non-conflicting movements are combined to form a *phase*, where the green light can be allocated to all movements in a phase simultaneously. Our goal is to select the best phase and decide its length for maximizing the intersection throughput and providing fairness among phases. The dynamic traffic control problem is defined as follows.

1) How do we calculate the passing rate for each movement so that the green light can be allocated to the movement with the highest pass rate for increasing the number of vehicles passing an intersection?
2) How do we combine non-conflicting movements to form a number of phases so that each phase can contain movements as many as possible for increasing the number of vehicles passing an intersection concurrently?
3) How do we calculate the passing rate of a phase and allocate the green light to the phase with the highest passing rate for maximizing the intersection throughput?
4) How do we prevent the phases with higher passing rates

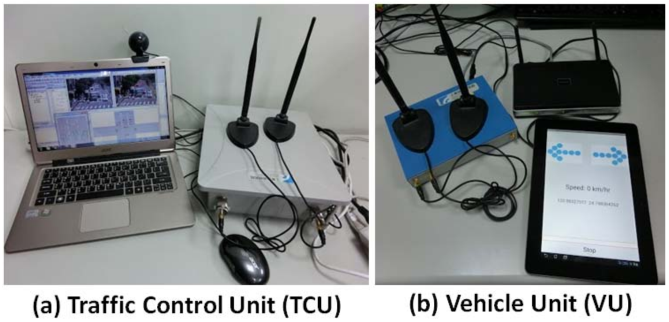

Fig. 3. LDTC hardware components.

from getting the green light again and again so that starvation of the phases with lower passing rates can be avoid for providing fairness among phases?

III. Prototype Implementation

We have developed a prototype of LDTC. Our proposed dynamic traffic control algorithm can be found in [7], which is to increase throughput and provide fairness at intersections. For throughput enhancement, instead of queue lengths, the passing rates of traffic flows are used to maximize the number of vehicles passing an intersection. For fairness provision, to avoid starvation, the priorities of traffic flows are increased with their waiting time at intersection. Our algorithm can be applied in all intersections with either dedicated tuning lanes or non-dedicated tuning lanes.

In our prototype, RSU and OBU are implemented by outdoor and indoor ITRI WAVE Communication Units (IWCUs [8]), as shown in Fig. 3(a) and Fig. 3(b), respectively. IWCU has two IEEE 802.11p interfaces and one Ethernet connector. Vehicle registration/deregistration operated in LDTC can send UDP packets via standard Linux socket APIs (e.g., bind(), sendto(), and recvfrom()). IWCU can convert UDP packets to WAVE short messages (WSMs) [9].

TCU is implemented by connecting an IWCU and a video camera with a notebook via Ethernet RJ-45 and USB ports, respectively, which is running on Windows 7 operating system, as shown in Fig. 3(a). The graphic user interface (GUI) and vehicle recognition are developed by Microsoft Visual C++ 2008 integrated development environment (IDE) and OpenCV [10], respectively. The GUI shows the road segment located by vehicles at the intersection, messages received from vehicles, and scheduling of traffic light timings.

VU is implemented by an Andorid Pad communicated with an IWCU and an OBD interface through Wi-Fi and Bluetooth, respectively, as shown in Fig. 3(b). The Ethernet connector of the IWCU is connected to a legacy Wi-Fi access point for communications with Android Pad and the 802.11p interfaces are set to WAVE/DSRC mode [11] for communications with TCU.

Fig. 4 shows the prototype demonstration of LDTC. TCU is installed at the intersection, as shown in Fig. 4(a). VU with an IWCU and a Bluetooth OBD-II interface is set up in a real car,

Fig. 4. Prototype demonstration.

as shown in Fig. 4(b) and Fig. 4(c). The vehicles approaching and stopping at the intersection are detected and represented by yellow and green squares, respectively, as shown in Fig. 4(d). The vehicle with VU is driven from one of four road segments at the intersection to register itself to TCU. At the same time, the lane position of a stopping vehicle detected by the video camera will be associated with the registration information received by TCU. For indoor demonstration, we use several video clips of approaching and stopping vehicles to simulate traffic conditions on one road segment at an intersection. A VU is used to register itself to TCU and trigger operations of LDTC with the car status including vehicle type and length, turning intention, and lane position.

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