Hybrid contraflow lane reversal approach for connected vehicles

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Abstract

Although the advent of connected vehicles (CV) has reshaped the urban traffic management strategies, little attention has been paid to the traffic throughput maximization problem by adjusting road configuration based on dynamic traffic condition at multiple intersections. In this paper, we model the vehicular traffic flow maximization problem as a maximum integer multi-commodity flow problem and propose a local intersection agent which maximizes traffic throughput by reversing the direction of a contraflow lane on an underutilized road segment. The agent detects unbalanced utilization of road segments and assesses the feasibility of lane reversal in collaboration with neighboring agents via communication between CVs or between CV and agents.

Keywords- Connected vehicles, Traffic management, Traffic flow maximization problem, Intersection agent, Dynamic lane reversal, Real-time traffic data

Ⅰ. Introduction

Dynamic lane reversal has been employed as an efficient way to overcome the logistical challenge in handling massive vehicular traffic during evacuation, where people are enabled to safely travel away from a hazardous site [1-0]. Among them in [6-9], partial lane reversal is considered where only a subset of the lanes in certain directions are reversed to enable timely handling of evacuees who need urgent care, e.g., elders. However, in such work no consideration has been given to congestion due to dynamic change in traffic volume during normal conditions.

Meanwhile, contraflow lane reversal has been exploited by some studies in managing dynamic traffic changes [10-15]. Zhou et al. have developed a self-learning contraflow lane system for controlling tunnel traffic to estimate real-time traffic demand for passing the tunnel and decide when to use contraflow to avoid having a bottleneck [10]. On the other hand, Autonomous vehicles (AVs) allows more frequent lane direction changes than human driving cars due to the prompt communication between a traffic management agent and AVs [13-15]. Although their algorithm factors in dynamically changing traffic condition, it does not consider turns and their conflicts at an intersection.

Unlike prior work, in this paper we first model the vehicular traffic flow maximization (TFM) problem as a maximum integer multi-commodity flow problem (MCF) and introduce a local intersection agent which opts to maximize outbound vehicular flows using dynamic lane reversal control while considering real-time traffic flows at a target intersection and its neighboring intersections.

II. Problem formulation

We opt to maximize traffic flow by dynamically adjusting central lane direction at a target intersection i_x based on the identified unbalanced vehicular traffic condition at its neighboring or distant intersections. The intersection i_x has roads linked to its adjacent intersections in four directions the north, south, west and east direction of i_x, denoted as i_x^N, i_x^S, i_x^W, and i_x^E, respectively, as seen in Figure 1.

In order to map the traffic maximization problem into MCF, we represent the road network as a flow network via a directed graph $G = (V, E)$ where V includes the intersections, i.e., $V = \{i_x, i_x^N, i_x^S, i_x^W, i_x^E\}$ and E consists of road segments, i.e., directed edges between i_c and other intersections in $V \backslash \{i_x\}$ and is divided into two groups; one includes incoming lanes, i.e., $\{d \in \{N,S,W,E\} \mid S(i_x^d, i_x)\}$ and the other, outgoing lanes from i_x, i.e., $\{u \in \{N,S,W,E\} \mid S(i_x, i_x^u)\}$. $S(i_x^d, i_x)$ and $S(i_x, i_x^u)$ are represented as a white and shaded arrow, respectively in Figure 1. By knowing the motion direction of vehicles and traffic volume at i_x's neighboring intersection, we can estimate how many vehicles are coming into

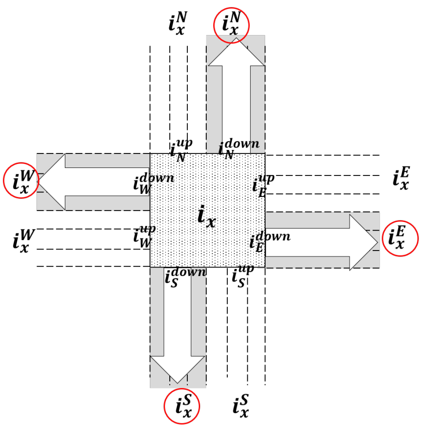

Figure 1. A four-leg intersection i_x has four pairs of an inbound and outbound road.

i_x from each of the four directions and vice versa. We denote such inbound and outbound traffic as *negative*, and *positive demands* i.e., $D(S(i_x^d,\ i_x))$ and $D(S(i_x,\ i_x^u))$, respectively.

Based on the two demand types, we denote the local flow of vehicles coming from i_x^d and going to i_x^u via i_x, as F_{du}, $d \neq u \in \{N, S, W, E\}$ and is defined as:

$$F_{du} = (i_x^d,\ i_x^u,\ n_{du}),$$

where

$$0 \leq\ n_{du}\ \leq min(|D(S(i_x^d, i_x))|,\ |D(S(i_x, i_x^u))|).$$

Then each F_{du} in a road network can be mapped into an individual commodity K_i in a flow network, $K_i = (src_i,\ dst_i,\ dmd_i)$, where src_i and dst_i are the source and sink of commodity *i* and dmd_i is the demand. src_i, dst_i, and dmd_i, are mapped into i_x^d, i_x^u, and n_{du}, respectively. Based on *G* and F_{du} we formulate TFM as MCF by showing that for each road, $S(i_x,\ i_x^u)$ or $S(i_x^d,\ i_x) \in$ *E*, F_{du} satisfies the three constraints that MCF holds, namely, capacity constraints, flow conservation at i_x, and demand satisfaction [16].

III. Dynamic lane adjustment (DLA)

the average vehicle waiting time via maximization of the road utilization. In order to assess the potential of lane reversal, ADLR employs an agent, LIM located at each intersection, i_x, which mainly carries out three tasks:

(i) road utilization monitor (RUM)
(ii) contraflow lane assessor (CLA)
(iii) dynamic lane adjustment (DLA).

RUM monitors changes in traffic on the inbound roads towards i_x, and detects congestion on $S(i_x^d, i_x)$ in collaboration with RUMs at neighboring intersections, i_x^d. When congestion is detected, CLA checks the possibility and viability of contraflow lane reversal in its counterpart outbound road, hereafter denoted as $\bar{S}(i_x, i_x^d)$ after querying the LIM at i_x^d for traffic status on the outbound roads. If lane reversal is found to be favorable by CLA, turning movement re-allocation should be performed by DLA to avoid diminished traffic throughput at i_x and i_x^d.

IV. Conclusion

DLR strives to increase traffic throughput by exploiting dynamic lane reversal of relatively underutilized road segments. The proposed agent consists of multiple local managers, namely, LIMs associated with the individual intersections. The set of LIMs cooperatively monitors real-time traffic data on individual intersections, re-configures the road with the feasibility check of lane reversal and adjusts turning movements for the updated road layout. The future work includes the performance analysis of the proposed LIM considering various road networks and traffic conditions.

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