Connected Autonomous Vehicles-enabled Traffic Management

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Abstract

Dynamic traffic management (DTM) at intersections have been the main focus in urban areas due to bottlenecks at junctions in road networks. DTM strategies in that context generally follow two methodologies, namely, time management and space management. Work on space management is generally done through road reconfiguration and is deemed to be instrumental for improving vehicular traffic throughput. The idea is to increase road utilization by (i) dynamic lane grouping which adaptively reassigns turn movements to lanes depending on real-time traffic demands, (ii) adaptively reversing contraflow lanes by considering variations in the traffic flow volume, and (iii) dynamic trajectory planning to factor in coordinated vehicle motion. In the paper, we discuss these techniques and summarize the state of the art.

Keywords- Dynamic traffic management, Connected autonomous vehicles, Dynamic lane grouping, Adaptively reversing contraflow, Dynamic trajectory planning

I. Dynamic Lane Grouping (DLG)

Traffic light signal scheduling which generally opts to assign short green duration to less traffic demands; however, low in-flow still may occupy unnecessarily large number of lanes while vehicles pile up for making a turn. DLG algorithms opt to overcome such a limitation and increase the utilization of existing road resources by balancing between lane capacity supply and changes in turning demands. DLG algorithms have gained significant attention due to its adaptability to road capacity constraints.

The main idea is to relieve traffic congestion and improve throughput and delay at intersections. The basic requirement for an effective DLG strategy is to estimate traffic volume for different movements, which cannot be provided by the inductive loop detection systems. With the help of various advanced traffic monitoring technologies, V2V, V2I, and I2I technologies such as road sensors, 802.11p, 802.16, i.e., WiMAX or cellular networks like LTE-V, or 3GPP Cellular-V2X(C-V2X), one can estimate the vehicle count per turn at intersections.

Some studies have focused on the fundamentals of the DLG concept and formulated the problem mathematically. The popular objective is to maximize lane utilization at an isolated intersection under traffic demand variation. These studies define a maximum lane flow ratio as the assigned flow divided by the saturation rate; they strive to minimize changes in such saturation rate among different movements, which could lead to a significant performance degradation at intersections. The effectiveness of DLG has been demonstrated using numerical analysis compared to fixed lane grouping for varying number of lanes, saturated/unsaturated flow, and fixed/adaptive traffic signal timing. The performance is assessed in terms of the average delay at an intersection [1]-[4].

Evaluation based on case studies has been conducted by various approaches to validate the performance of DLG. Using microscopic traffic simulation, the benefits of a DLG strategy has been demonstrated and compared to the conventional fixed lane grouping in terms of mobility and sustainability [3]. The performance of DLG is assessed using the average vehicle delay, the number of stops during a trip, the average fuel consumption per vehicle, the average rate of pollutant emissions such as carbon monoxide (CO), hydrocarbons (HC), and oxides of nitrogen (NOx) and CO2 per vehicle. Finally, it has been shown that the impact of DLG grows as the traffic volume and the frequency of the turn pattern varies; a DLG strategy is effective in balancing lane flow ratios and reducing intersection crossing delay and consequently, energy and pollutants emission. Moreover, an automatic screening tool has been developed to identify the intersections for which DLG is advantageous [4].

II. Dynamic Lane Reversal (DLR)

Contraflow lane reversal is used in big cities during rush hours; such scheduling is clearly static and cannot cope with variation of the traffic intensity. DLR would be logistically complicated for traffic involving human-driven vehicles since the flow direction cannot be switched until the lane is empty; often the police has to be engaged to ensure that. With the emergence of Connected autonomous vehicles (CAVs), DLR is deemed to be a very viable option since autonomous vehicles can rapidly switch out of the designated lane for flow reversal due to the automatic motion control and the prompt V2I and V2V communication.

A number of techniques have been proposed for DLR in CAV [5]-[7]. Among them, in [5] DLR in collaboration with autonomous intersection management has been proposed, where the total traffic volume on a road is monitored every two seconds; the road capacity is expanded by reversing the direction of a lane r on the paired road r_dual if the traffic demand on r is 1.5 times larger than or equal to that of r_dual. Such work has demonstrated how CAV enables efficient utilization of road infrastructure.

Meanwhile, some DLR approaches have been specific to particular road layouts and cannot be generalized to other layouts [8]-[11]. The focus of Li et al. [8] is on a signalized intersection with six lanes and two additional reversible center lanes. Only four scenarios are considered for typical urban morning and evening peak-hours. In [9][10], a signalized diamond interchange is considered, where the proposed DLR approaches strive to handle the concern of space limitation for different turns in order to reduce oversaturation at the interchange.

On the other hand, work in [11] focuses on the applicability of DLR to exist lanes for dynamic left-turn traffic. With the help of an additional traffic light (pre-signal) installed at the median opening, exit lanes for left-turn control problem was formulated as a mixed-integer nonlinear program, in which the geometric layout, main signal timing, and pre-signal timing were integrated and transformed into a series of mixed-integer linear programs. The results have shown significant growth in intersection capacity and reduction of traffic delay, especially under high left-turn demand.

III. Dynamic Trajectory Planning (DTP)

The vehicular traffic assignment for the traditional human-driven vehicles is mainly derived by the stochastic nature of the problem that it is subject to uncertainties related to perception and reaction times of drivers and human based error. Such uncertainty can be mitigated in CAV. Nonetheless, CAV raises new issues given the fine-grained controllability of autonomous vehicles. Basically, the spacing between autonomous vehicles can be significantly reduced enabling a set of vehicles to travel as a platoon. Thus, forming a platoon, joining and departing of an existing platoon, and setting the appropriate vehicle configuration are unique challenges in the case of CAV. In essence, the vehicles have to collectively determine speed, acceleration, and optimal spacing between them, subject to safety and road condition constraints.

Therefore, DTM will not only have to optimally assign traffic but also have to find the optimal vehicle trajectories. Indeed, the path selected or assigned by routing models in DTM will be subject to the multi-CAV motion planning for autonomous or mixed traffic scenarios. CAV motion planning is categorized in [12][13] into four hierarchical classes:

(1) route planning: it aims to find the best global route for given OD pairs and corresponds exactly to the traditional traffic assignment. The individual vehicular route is derived based on current and/or expected traffic statistics and does not consider obstacles, road geometry, etc.

(2) path planning: it considers the constraints of individual road segments that connect the origin and the destination and opts to cope with obstacles and specific flow constraints, e.g., road construction.

(3) maneuver planning: it determines the appropriate decision in each step including 'going straight', 'going left', etc. considering the position and speed of the CAV while taking into account the path that is specified from path planning.

(4) trajectory planning: it governs the motion of the vehicle and determines the vehicle's transition from one feasible state to another considering road obstacles and the vehicle's kinematic.

IV. Conclusion

We have discussed about three groups of traffic management for connected autonomous vehicles. The technolgoies introduced in this paper will be continuously enhanced and expecteed to introduce new applications in the future.

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