Macroscopic Traffic Dynamics with Dual Perimeter Control and External Routing

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Extended abstract submitted for presentation at the hEART 2018 7th Symposium
Sept. 5–7, 2018, Athens, Greece

Word count: 1184 words (excluding the references)
March 15, 2018

Extended abstract

In the last decade, efforts have been taken to represent the network traffic flow model by using Macroscopic Fundamental Diagram (MFD). The MFD representation simplifies the task of predicting traffic flow dynamics for large-scale urban networks, as it provides combined relationships between the crucial traffic variables of the urban network. Initially, the physical model of the MFD was proposed by Godfrey (1969), however, its experimental evidence was provided later by Geroliminis and Daganzo (2008) for the congested urban network in Yokohama. The MFD concept has been employed to design control policies keeping in the mind to improve urban traffic mobility and travel time in large urban networks. The perimeter control strategies have been developed for single and multi-reservoir urban networks, see Haddad (2017) and references therein. The urban MFD concept is also been utilized to improve mobility via route guidance (Yildirimoglu et al., 2015) and feedback-based gating (Keyvan Ekbatani et al., 2016). The combination of optimal regional route guidance and perimeter control using economic Model Predictive Control (MPC) has developed to reduce congestion and Total Time Spent (TTS) see Sirmatel and Geroliminis (2017) and references therein. In this approach, optimal routes are obtained by the system and so they do not study how users react to perimeter control. Urban traffic networks have a hierarchical structure which essentially consists of freeways and urban roads providing the interrelated infrastructure for mobility and accessibility. The urban network and the freeway are inherently coupled, but they have different traffic flow dynamics which makes control problem challenging. Some recent work on the control of a large-scale mixed traffic network with freeway route has shown the great importance of perimeter control combined with route choice (Haddad et al., 2013).

In this work, we focus on the combination of perimeter control and user adaptation through routing (user equilibrium) on an urban traffic network. Presented results indicate that the perimeter control and user equilibrium-based routing can significantly improve the congestion state of the network and the total time spent even when considering the side effects outside the perimeter related to user changes in route choice. The network under consideration comprised of a homogeneous urban reservoir with one internal route, two external routes, and a freeway, as depicted in Fig. 1. The traffic dynamics of a reservoir with well-defined speed-MFD $V(n) = P(n)/n$ (in [m/s]) is given by accumulation-based model proposed in Mariotte and Leclercq (2018), where n (in [veh]) is the total accumulation. This model considers different trip lengths inside the reservoir, proper treatment of input and output flow of the reservoir based on the constraints on production, and accounts for the effect of internal trips. The reservoir entry is the aggregation of all individual entry nodes of the network; similarly, the reservoir exit aggregates all the exit nodes. Through the entry is defined the total effective inflow $q_{in}(t)$ and through the exit, the total effective outflow $q_{out}(t)$ (in [veh/s]).

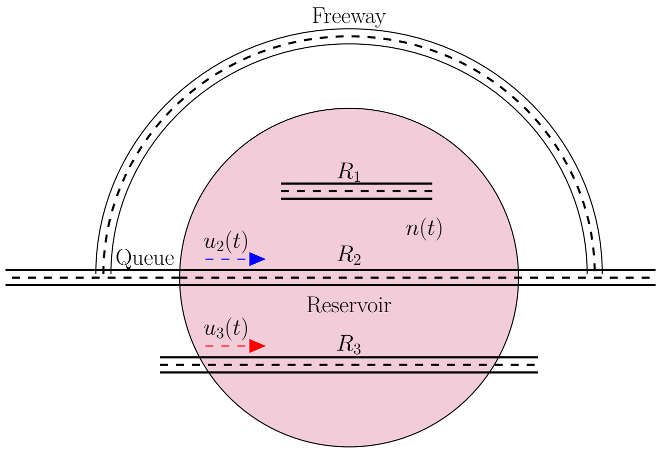

Figure 1: Single reservoir network with freeway: one internal route (R_1), two external routes (R_2 & R_3), two perimeter control inputs $u_2(t)$ and $u_3(t)$, and one measured output $n(t)$ as total accumulation inside the reservoir.

For the perimeter control, we designed the two PI controllers to track the desired set-point of the total number of vehicles inside the reservoir ($n(t)$) by manipulating inputs of the routes 2 and route 3 while the input to the internal trip route 1 is kept constant. It is well-known that the perimeter control results in queueing vehicles at the periphery of the reservoir. The consequence is that the queue is diverted to the freeway by employing the routing strategy assuming user equilibrium. In order to show the significance of perimeter control its impact on traffic dynamics, we present a case study with configuration given in Table 1. To show the performance of dual perimeter control during congestion, we imposed the constraints on the outflow of the route 3 i.e. $q_{out,3}$.

For the simulation, we considered various demand levels ranging from non-congested to gridlock conditions. For the perimeter control, we compare the results of the uncontrolled case (denoted as UC) with perimeter control case (denoted as PC). The PI controllers are designed with back-calculation anti-windup scheme and controller gains are tuned by the trial-and-error method to balance both the inputs ($u_2(t)$ and $u_3(t)$) with saturation limits. The perimeter control is applied to track the desired set-point of total accumulation inside

Table 1: Values of the parameters used in the case study.

Parameter	Value	Unit
Reservoir route lengths	[1600 1500 2000]	m
Reservoir maximum production	3000	veh.m/s
Reservoir free-flow speed	15	m/s
Reservoir jam accumulation	1000	veh
Reservoir critical accumulation	400	veh
Freeway length	20000	m
Freeway free-flow speed	25	m/s
Freeway free-flow travel time	800	s

the reservoir and set-point is kept as the critical accumulation to avoid congestion inside the reservoir. Fig. 2 shows the response of uncontrolled (UC) and controlled (PC) case for the total accumulation inside the reservoir for a given demand pattern. It can be clearly seen that in uncontrolled case, reservoir goes to the highly congested state whereas PI controllers keep total accumulation at the desired level.

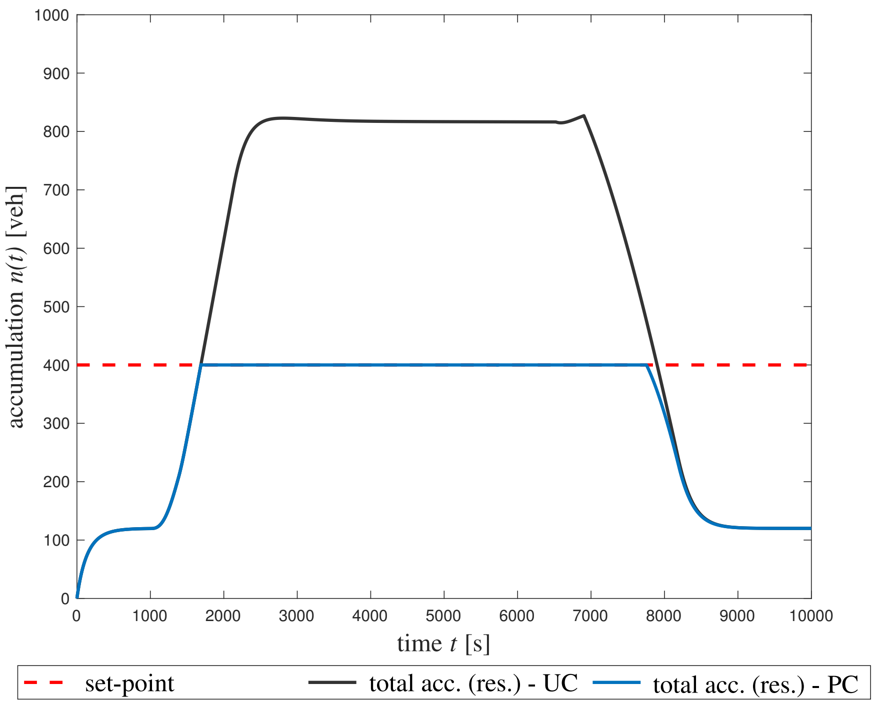

Figure 2: Performance comparison of uncontrolled case and perimeter control (PI controller) case, for set-point tracking of total accumulation inside the reservoir.

To see the impact of dual perimeter control inside and outside of the reservoir, the detailed results of Travel Time (TT) for all the routes inside the reservoir and the queues formed outside the reservoir are shown in Fig. 3. Due to the constraint on the outflow of the route 3, fewer vehicles are entering to the reservoir which forms the long queue outside the reservoir. As a consequence of constraint, the travel time in the uncontrolled case is more than the travel time for route 3 and there is a long queue outside the reservoir which also increase the travel time for vehicles waiting to enter in the reservoir. For the route 2 when the predicted travel time inside the reservoir and queue matches with the freeway travel time, vehicles take the freeway to reach the destination. For the perimeter control case, we can see the improvements in travel time for both the routes. In case of route 2, we can see the reduction in the queue but for route 3, there is a minor reduction in the queue and that is because of the outflow constraint.

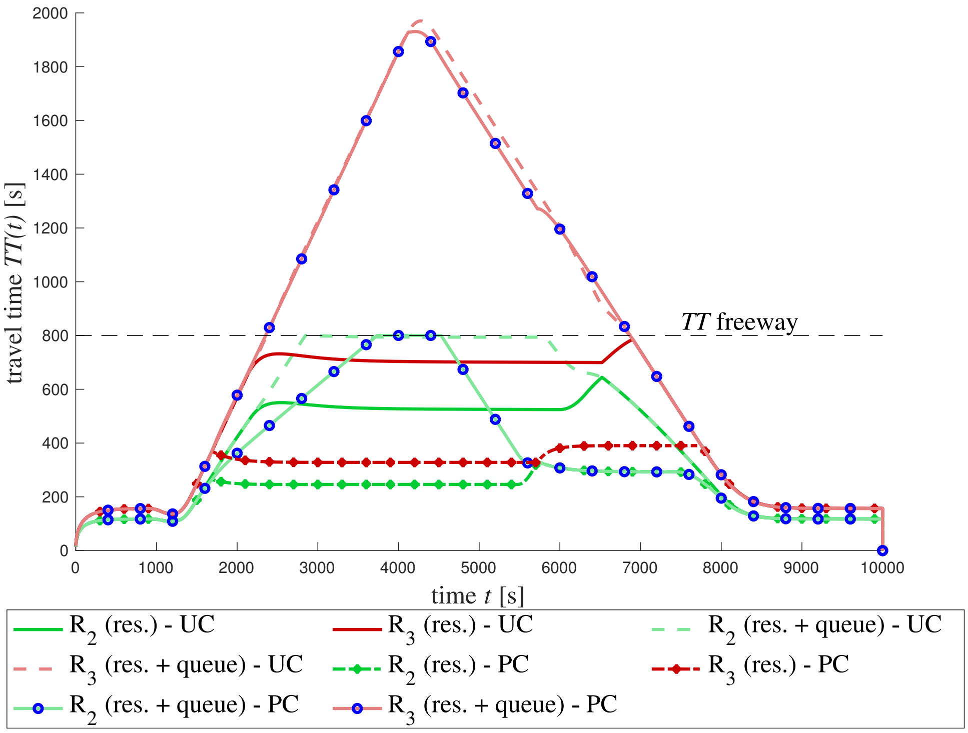

Figure 3: Comparison of travel time on different routes (inside and outside the reservoir) for uncontrolled (UC) and controlled case (PC).

Fig. 4 depicts the impact of perimeter controller on the total time spent for vehicles inside the reservoir, in the queue, and traveling on the freeway. We can see significant improvement in the time spent during congestion and unloading for dual perimeter control case as compared to the uncontrolled case. This is due to the improvements in travel time for route 1 and 2. In case of route 3, total time spent is same for controlled and uncontrolled case due to the outflow constraint.

Overall, perimeter control and routing (assuming user equilibrium) approach help to improve congestion, total time spent for trip completion, and queue length. The results of this work provide deep insights into the traffic dynamics of the cities with freeway and the impact of perimeter controller inside and outside of the urban network. In our future work, we will analyze the impact of perimeter control on the environment.

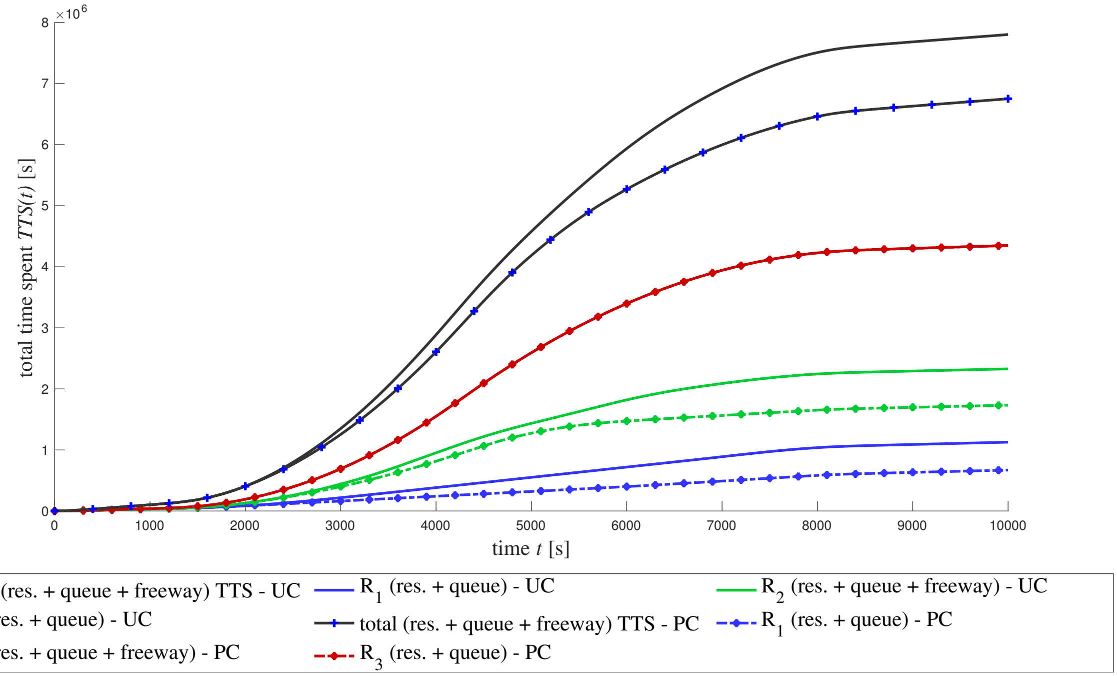

Figure 4: Comparison of total time spent on different routes (inside and outside the reservoir and on the freeway) for uncontrolled (UC) and controlled (PC) case.

Keywords: Macroscopic Fundamental Diagram (MFD), Traffic dynamics, accumulation-based model, freeway, Dual perimeter control, PI controller

Acknowledgment

This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation program (grant agreement No 646592 – MAGnUM project).

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