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Lattice hydrodynamic model based traffic control: A transportation cyber–physical system approach

Hui Liu [a,b,*], Dihua Sun [a,b], Weining Liu [a,c]

[a] *Key Laboratory of Dependable Service Computing in Cyber Physical Society of Ministry of Education, Chongqing University, Chongqing 400044, China*

[b] *College of Automation, Chongqing University, Chongqing 400044, China*

[c] *College of Computer Science, Chongqing University, Chongqing 400044, China*

HIGHLIGHTS

- A new traffic control method is proposed through a transportation cyber–physical system view.
- Only one lattice site needs to be controlled by the use of the proposed control scheme.
- Numerical simulations are carried out to reveal the effectiveness of the proposed control scheme.

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ABSTRACT

Lattice hydrodynamic model is a typical continuum traffic flow model, which describes the jamming transition of traffic flow properly. Previous studies in lattice hydrodynamic model have shown that the use of control method has the potential to improve traffic conditions. In this paper, a new control method is applied in lattice hydrodynamic model from a transportation cyber–physical system approach, in which only one lattice site needs to be controlled in this control scheme. The simulation verifies the feasibility and validity of this method, which can ensure the efficient and smooth operation of the traffic flow.

1. Introduction

The problems of traffic congestion, pollution, and people safety are becoming more and more important due to the increase in the number of cars and it has been attracting the attention of scientists and engineers from several decades. So how to control the traffic flows and to prevent or reduce traffic jams, or more generally to improve the performance of the traffic system is very meaningful.

In the past decade, a variety of modeling approaches have been studied from different points of views such as hydrodynamic models, car-following models, and cellular automata models for understanding the formation of traffic congestion [1–7]. However, the lattice hydrodynamic model was firstly proposed by Nagatani [3] in 1998 incorporating the ideas of macroscopic as well as microscopic traffic flow models to analyze the jamming transition evolution of traffic flow. Because of its simplified nature of modeling that a lot of extended lattice models have been proposed by considering the different real situations [8–23]. For instance, Peng et al. [8] and Tian et al. [9] studied the performance of lattice model by considering the effects of the honk and driver's memory. The effects of density difference and multiple density difference were

* Corresponding author at: College of Automation, Chongqing University, Chongqing 400044, China.
E-mail address: hly_huiliu@163.com (H. Liu).

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considering in Refs. [10–12]. Furthermore, the one-dimensional lattice hydrodynamic traffic model was also extended to multi-dimensional networks by manly authors [13–18] to name just of few.

Recently macroscopic models are found more suitable in controlling the traffic dynamics on road networks. Ge et al. [24] designed a feedback control method for lattice hydrodynamic model to suppress the traffic jam and it is found that feedback control plays an important in reducing the congestion even at macroscopic level. Then, Redhu et al. [25] proposed a delayed-feedback control method for one-dimensional lattice hydrodynamic traffic model to suppress the traffic congestion. Li et al. [26] proposed a delay feedback control scheme for the lattice hydrodynamic model by considering the effects of the local density change rate difference between adjacent lattice sites. They found that the control methods are useful to suppress the traffic jam. However, the aforementioned control methods are useful in the condition that all the lattice sites in transportation system can be controlled. In fact, fewer lattice sites need to be controlled and which is cheaper and easier implementation for intelligent transportation system. In contrast to the aforementioned literature, the main focus in this paper is on how to control only one lattice site for suppressing the traffic jam. And this paper is organized as follows. Section 2 introduces the lattice hydrodynamic model as used in this paper. Next, Section 3 proposes a control strategy from a transportation cyber–physical system approach, upon which Section 4 presents experimental results. Finally, Section 5 summarizes the main conclusions.

2. The lattice hydrodynamic model

The first lattice hydrodynamic model was proposed by Nagatani [3] for analyzing the density wave of traffic flow on a unidirectional road and is given by

$$\partial_t \rho_j + \rho_0 \left(\rho_j v_j - \rho_{j-1} v_{j-1}\right) = 0 \tag{1}$$

$$\partial_t \left(\rho_j v_j\right) = \alpha \rho_0 V\left(\rho_{j+1}\right) - \alpha \rho_j v_j \tag{2}$$

where ρ_0 is the average density; j indicates site-j on the one-dimensional lattice; ρ_j and v_j, respectively, represent the local density and velocity at site-j at time t; α is the sensitivity of drivers; $V(\rho)$ represents the optimal speed of the traffic flow at the density of ρ and it is taken as

$$V(\rho) = \frac{v_{\max}}{2}\left[\tanh\left(\frac{1}{\rho} - \frac{1}{\rho_c}\right) + \tanh\left(\frac{1}{\rho_c}\right)\right] \tag{3}$$

where $v_{\max}$ and ρ_c denote the maximal velocity and the safety critical density, respectively.

Based on linear stability analysis, the stability condition of lattice hydrodynamic model is given by Refs. [3,24]

$$\alpha > -2\rho_0^2 \Lambda \tag{4}$$

where $\Lambda = {}^{\partial V(\rho)}/_{\partial \rho}$. If the stability condition is met, then the flux fluctuation in a single lane would not propagate backwards with an increase of disturbance, which can lead to traffic jams [24]. In general, traffic system instabilities refer to stop-and-go waves which propagate upstream against the flow of traffic without an apparent bottleneck, and have two sharp interfaces: one at which vehicles decelerate and one at which vehicles accelerate. According to the relationship between the stability condition and traffic jams, a typical control scheme for every lattice site is given by Refs. [24–26]

$$\partial_t \left(\rho_j v_j\right) = \alpha \rho_0 V\left(\rho_{j+1}\right) - \alpha \rho_j v_j + u_j \tag{5}$$

where u_j is the control term, which is usually designed by the consideration of ego lattice site and their neighbors' density and flow [24–26].

For simplicity, consider the traffic flow model equations (1) and (2), eliminating the variable v_j, the lattice hydrodynamic model is given by

$$\partial_t^2 \rho_j = \alpha \rho_0^2 \left(V\left(\rho_j\right) - V\left(\rho_{j+1}\right)\right) - \alpha \partial_t \rho_j \tag{6}$$

where the propagating process and evolutive characteristics for lattice sites' density can be got.

3. The proposed control scheme

In order to alleviate traffic congestion, information and communication technologies are now widely used in transportation systems by integrating sensors, control units and automatic technologies with microchips to enable them to communicate with each other through wireless technologies. Thus the modern transportation systems can be characterized by the tight coupling between transportation physical space (vehicle dynamics) and transportation cyber space (sensor networks and communication networks). As illustrated in Fig. 1, a typical transportation system consists of two planes, a physical plane and a cyber plane. The physical plane describes the vehicle mobility under the constraints of traffic environment, while the cyber plane describes the information of the transportation physical system and the communication networks.