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Effects of the amount of feedback information on urban traffic with advanced traveler information system

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ABSTRACT

In a real traffic system, information feedback has already been proven to be a good way to alleviate traffic jams. However, due to the massive traffic information of real system, the procedure is often difficult in practice. In this paper, we study the effects of the amount of feedback information based on a cellular automaton model of urban traffic. What we found most interesting is that when providing the traffic information of a part of a road to travelers, the performance of the system will be better than that providing the road's full traffic information. From this basis, we can provide more effective routing strategy with less information. We demonstrate that only providing the traffic information of about first half road from downstream to upstream can maximize the traffic capacity of the system. We also give an explanation for these phenomena by studying the distribution pattern of vehicles and the detailed turning environment at the intersections. The effects of the traffic light period are also provided.

1. Introduction

With the rapid development of economy, traffic congestion is becoming more and more serious in modern cities. In order to mitigate the traffic congestion and improve the efficiency of road network and airport networks, various models and mechanisms have been proposed, such as optimization of traffic signals, providing efficient routing paths, and advanced traveler information systems [1–4].

Recent research on the network traffic of information packets indicates that the network capacity could be remarkably improved by optimizing the routing strategy [5–9]. Scellato et al. have also studied the traffic of urban street networks [10], and show that a global traffic optimization could be achieved by choosing a good routing strategy. However, the traffic lights are not considered in their model, which has already been proven to play a key role in the performance of the urban traffic system.

In order to explore the performance of urban traffic networks clearly, many traffic flow models have been put forward, including macroscopic kinetic models and microscopic cellular automaton models. For example, in Ref. [11], Fermo et al. propose a new mathematical model of vehicular traffic based on the generalized kinetic theory, which can simulate various realistic scenarios. Compared to this, the cellular automata models simulate the traffic flow with discrete time and space. Due to flexible evolution rules and high computation efficiency, the cellular automata models are well suited for traffic simulation [12].

In 2011, Li et al. propose an urban traffic model based on the cellular automaton model [13]. Since the origin-destination trips and traffic lights are both considered in this model, the routing strategies approaching to reality can be studied. They find that the traffic information feedback can help the travelers to pick their own paths and alleviate the traffic jam effectively. After that, Jiang et al. study the network operation reliability (NOR) in such system [14]. They find that the adaptive traffic signal is able to remarkably enhance the network operation reliability (NOR) and sometimes the average velocity and the flow as well.

However, the collection, processing and delivering of a lot of traffic information also cost a lot in practice. Therefore, there are still many questions need to be answered before applying these methods. For example, how much information we need to choose a good path? Furthermore, can we use less information to make the system perform better? For the answers to these questions, we study the effects of the amount of feedback information in this paper. Interestingly, we find that only providing the traffic information of about first half road from downstream to upstream can maximize the traffic capacity of the system.

The paper is organized as follows. In the next section, the simulation model and routing strategies will be introduced. In Sec. 3,

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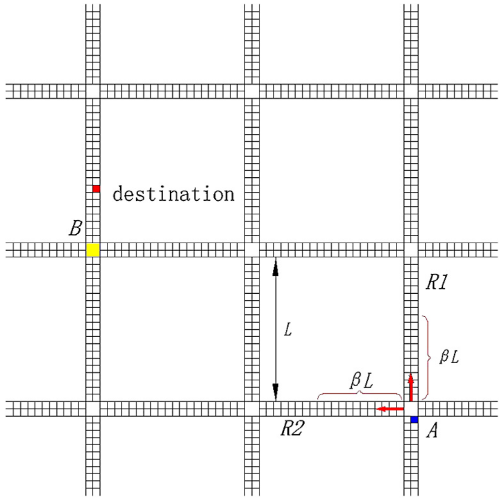

Fig. 1. (Color online.) An example of the Manhattan-like urban traffic system. All the roads are divided into cells, and each cell can be empty or occupied by a vehicle, assuming that all the vehicles go along the shortest paths to their destinations. In this way, the vehicle at intersection A (indicated by blue) must go to the yellow intersection B first, and then go to its destination (indicated by red). So, there are two roads $R1$ and $R2$ to access for the vehicle at intersection A. L is the length of the road, and βL is the length of road used for information feedback.

the simulation results will be discussed. Finally, conclusion will be given in Sec. 4.

2. Model

In this paper, we study the traffic flow in a Manhattan-like urban traffic system based on the cellular automaton model as shown in Fig. 1. The system contains $N \times N$ intersections, and two adjacent intersections are connected by a road with two lanes for two opposite directions, respectively. Vehicle driving is restricted to the right lane. Each lane is divided into L cells, numbered $1, 2, \cdots, L$ from downstream to upstream. In addition, the intersection is treated as one cell.

For simplicity, we assume that the synchronous traffic lights with fixed period are set at each intersection. It means that the traffic light state of all roads with same direction is consistent at same moment. For each phase, the traffic light keeps green for one incoming lane and red for the other three incoming lanes for T time steps. So each traffic light has four phases, a total of $4T$ time steps for one period. When the light is green, vehicles in the corresponding incoming lanes could go straight ahead, turn left or right, or make a U-turn.

Our model is based on the Nagel–Schreckenberg (NaSch) rules [12]. We extend the NaSch model to urban road networks by considering the origin-destination of vehicles, traffic lights at the intersections, routing and navigation of vehicles, the information feedback of advanced traffic information systems. These features are important for studying the dynamics of urban traffic system. Vehicles travel in the system following the Nagel–Schreckenberg rules [12] as follows:

- Acceleration: $v_i \to \min(v_{max}, v_i + 1)$;
- Deceleration: $v_i \to \min(d_i, v_i)$;
- Random brake: $v_i \to \max(v_i - 1, 0)$ with a braking probability p;
- Movement: $x_i = x_i + v_i$.

Here, v_{max} is the maximum velocity of vehicle, x_i is the position of the ith vehicle in a lane and d_i is the number of empty cells ahead of this vehicle. That is, except for the leading ones in each lane, $d_i = x_{i+1} - x_i - 1$.

For the leading vehicles in each lane, the definition of d_i is as follows:

1. Traffic light is green
   - If the desired outgoing lane is in jam or the intersection is occupied at the moment, d_i is the number of empty cells ahead to the intersection.
   - Otherwise, d_i is the number of empty cells ahead to the last vehicle of the desired outgoing lane.
2. Traffic light is red
   - d_i is the number of empty cells ahead to the intersection.

At each intersection, when the last two cells of an outgoing lane are simultaneously occupied, the outgoing lane is considered jammed. Vehicles choosing the jammed lane are not allowed to enter the intersection to avoid hindering vehicles in other lanes.

Initially, all vehicles are distributed in the system randomly with a randomly chosen destination. When a vehicle reaches its destination, a new cell is chosen randomly from the system as the new destination, excluding the cells in the current lane. In this way, the number of vehicles is fixed.

Next, we give the details of the routing strategy used in this paper. For simplicity, we assume that all vehicles go along the shortest paths from their origins to destinations. However, in the system as that shown in Fig. 1, there are more than one shortest path between most of the origin-destination cells. For example, as shown in Fig. 1, when a vehicle reaches intersection A, there are two choices: going straight (lane $R1$) or turning left (lane $R2$). Without traffic information feedback, the vehicle will choose a lane randomly.

For the case with traffic information feedback, we suppose that, at each intersection, the information feedback system can provide the average velocity of the vehicles in the last βL cells (from downstream to upstream) of each outgoing lane. Therefore, the traveler can choose the lane with the larger average velocity as the targeted lane. It is obvious that fraction β evaluates the amount of feedback information. A larger β will increase the cost of the collection and processing of traffic information.

3. Simulation results and discussion

The system size is set as $N = 24$ and the length of the roads is $L = 100$ cells. So the system can hold a maximum of 220800 vehicles. The maximum velocity of vehicles is $v_{max} = 3$ and the probability of random brake is $p = 0.1$. The period of traffic lights is $T = 20$ unless otherwise stated. The simulation results shown here are obtained after discarding the first 10^5 time steps (as transient time) and then averaging over the next 10^4 time steps.

3.1. General results

In this section, we study a simple case that $\beta = 0.5$ first. That is, the information feedback system only provides the average velocity of the vehicles in the second half of each outgoing lane (from downstream to upstream), as shown in Fig. 1. In Fig. 2, we plot the average velocity $\langle v \rangle$, the average traffic flow $\langle J \rangle$, and the average arrival rate $\langle A \rangle$ as a function of the vehicle density ρ. Here, the traffic flow $\langle J \rangle$ of a lane is the number of vehicles going into or out the lane per time step, and the average is over all the lanes in the system. The average arrival rate $\langle A \rangle$ is the number of vehicles reaching their destinations per time step. The vehicle density ρ is the fraction of each cell with a vehicle in it.

For comparison, we also give the simulation results for $\beta = 0$ (without information feedback system) and $\beta = 1$ (with information feedback of the whole lane). We can find that there is a typical density labeled as ρ_c in Fig. 2, above which the system turns into

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