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Dynamic origin-to-destination routing of wirelessly connected, autonomous vehicles on a congested network

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HIGHLIGHTS

- Congestion of autonomous vehicles traveling on a square lattice of roads is simulated.
- Wireless communication among all vehicles is assumed.
- Optimal routes from an origin to a destination are found using different algorithms.

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ABSTRACT

Up-to-date information wirelessly communicated among vehicles can be used to select the optimal route between a given origin and destination. To elucidate how to make use of such information, simulations are performed for autonomous vehicles traveling on a square lattice of roads. All the possible routes between the origin and the destination (without backtracking) are of the same length. Congestion is the only determinant of delay. At each intersection, right-of-way is given to the closest vehicle. There are no traffic lights. Trip times of a subject vehicle are recorded for various initial conditions using different routing algorithms. Surprisingly, the simplest algorithm, which is based on the total number of vehicles on a route, is as good as one based on computing travel times from the average velocity of vehicles on each road segment.

1. Introduction

Wirelessly connected, autonomous vehicles offer the potential for better vehicle safety and improved traffic flow, among other benefits [1–8]. From a research perspective, these systems present an interesting challenge to determine how to exploit them in an optimal manner. One such topic is to find the fastest path between a given origin (O) and destination (D) amongst multiple routes with time varying congestion. Many papers [9–12] have been published on the "OD" problem, frequently with the emphasis on mathematical techniques, such as the Dijkstra algorithm [13], to find the fastest route in a computationally efficient way. In the presence of congestion, the fastest route might not be the shortest route. Researchers tend to use measurements of flow to estimate travel time on individual road segments. A common practice is to use a function (travel time as a function of flow) from the US Bureau of Public Roads [14]. The present paper is a report of simulations to determine the fastest OD route for autonomous vehicles with wireless connections navigating through congestion of their own making.

Wireless communication among vehicles can provide useful information. The simplest possibility is just broadcasting the number of vehicles on each link. The average velocity of vehicles on any link could also be provided. In this paper I consider how information from connected vehicles on a road network can be used to predict the optimal route for a given

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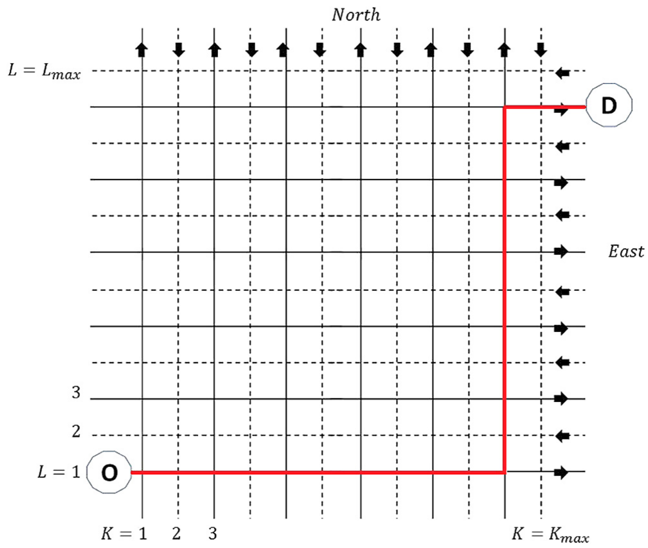

Fig. 1. The square-lattice network of links used in simulations. Each road is a single, one-way lane with no traffic lights at intersections. East bound roads are labeled as: $L = 1, 3 \ldots L_{\max} - 1$; West bound: $L = 2, 4 \ldots L_{\max}$; North bound: $K = 1, 3 \ldots K_{\max} - 1$; South bound: $K = 2, 4 \ldots K_{\max}$ The subject vehicle travels from the origin in the lower left corner to the destination which is east of intersection $(K_{\max}, L_{\max} - 1)$. Trip travel time begins when the subject vehicle crosses intersection (1, 1). The distance from the midpoint of one intersection to the next is $N_c D$ where N_c is an integer (100 in simulations) and $D = 7.5$ m. The default route is indicated by red lines. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

OD. The network studied is a square lattice of identical links (single lane, one way), so each route to be analyzed is the same length (assuming no north-bound to west-bound or east-bound to south-bound turns). Congestion is the only factor that determines travel time. Vehicles are taken to be identical, autonomous cars equipped with adaptive cruise control, which is consistent with the assumption of an ideal wireless connection [15]. The network is simple enough that enumerating paths is straightforward. The emphasis of this research is to use information from wireless connections about realistic congestion caused by many vehicles moving on the network, rather than a surrogate like flow at an intersection, when attempting to find optimal routes.

The model is described in Section 2 of the paper. Simulations for different algorithms are compared in Section 3. The nature of the congestion through which the subject vehicle travels is also described in Section 3. Conclusions and discussion are presented in Section 4.

2. The model

The goal is to discover routing algorithms that reduce the travel time from a given origin to a given destination in the presence of traffic congestion. Each vehicle is taken to be autonomous with wireless connection to the subject vehicle, whose trip times from origin to destination are recorded. Congestion occurs on the network of roadways when sufficient numbers of vehicles are present. Except for the subject vehicle, all vehicles travel on the roads with a non-zero probability to turn randomly at intersections. The road network is a square lattice of single-lane, one-way roads (Fig. 1); each link is of the same length $N_c D$ where N_c is an integer and D is the minimum distance between vehicles at zero velocity. The east–west roads are labeled by L and the north–south roads are labeled by K. Odd values of L denote roads running east and even values west. Likewise odd values of K indicate north and even south. The subject vehicle travels from the lower left to the upper right corner of the lattice using only east bound and north bound roads. Travel time begins when the subject vehicle crosses intersection $(K, L) = (1, 1)$ and ends when it reaches a point east of $(K_{\max}, L_{\max} - 1)$. I take $K_{\max} = L_{\max}$ to be even integers. The boundary conditions are periodic so that the number of vehicles is conserved.

East-bound vehicles obey the following equations of motion:

$$\frac{dv_i}{dt} = \min\left\{a_{accel}, a_i^d\right\}, \tag{1a}$$

$$a_{accel} = 1\ \text{m/s}^2, \tag{1b}$$

$$a_i^d = \alpha\left[\frac{x_{lead} - x_i - D}{h_d} - v_i\right] + k_d\left(v_{lead} - v_i\right). \tag{1c}$$

Here "*lead*" refers to the vehicle immediately in front of vehicle i or it can be a stopping point at an intersection if vehicle i does not have the right of way, which is determined by the closest vehicle approaching the intersection. Note that at