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An intersection-to-intersection travel time estimation and route suggestion approach using vehicular ad-hoc network

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ABSTRACT

Estimation of time-dependent travel time in an urban network is a challenging task due to the interrupted nature of vehicular traffic flows. A novel concept of intersection-to-intersection (I2I) real-time travel time estimation (TTE) and route suggestion model based on vehicular ad-hoc network (VANET) technology is proposed for enabling the smart transportations in smart city. The system components, communication protocol and collaborative intelligence concept are designed to facilitate real-time vehicular applications. Vehicles equipped with an on-board unit (OBU) send TTE requests to the road side unit (RSU) and share their real-time information, including traveled path and average speed, and the RSU responds with the suggested shortest route as well as the estimated travel time. In order to efficiently share real-time traffic information among RSUs, a propagation-based RSU-to-RSU (R2R) data exchange algorithm and a traffic information super-matrix data structure are designed. These reduce the complexity from $O(N^2)$ for a traditional broadcast approach to $O(N)$. Real data collected from a GPS-based taxi dispatching system is applied to evaluate the accuracy of the proposed TTE model and the performance of the suggested route. The experimental results show that the average mean absolute error percentage (MAPE) of the proposed TTE model is 13.6% compared to real taxi journeys, which indicates that the performances of the suggested routes are good. The TTE of the suggested paths has the possibility of being 82.2% better than the paths traveled by taxi, and the travel time is thus reduced by 15.9% on average over a year.

1. Introduction

Intelligent transportation system (ITS), enabled by vehicular communications among vehicles, people (i.e., smart phones), sensors, road-side units, and traffic management centers, are vital for the development of smart cities. Travel time estimation (TTE) is one of the most practical functions in advanced traveler information systems (ATIS), and also contributes to several modern ITS management systems, such as advanced traffic management systems (ATMS), commercial vehicle operations (CVO) and emergency management systems (EMS) [1]. With accurate traffic time estimation, travelers can make better decisions regarding traffic routes and so reduce travel time uncertainty. For logistics operators, accurate TTE can avoid congestion and thus reduce transport costs and increase service quality. For ATMS managers, travel time information is a meaningful index of traffic system operations. Moreover, the use of travel time information can help decrease the volume of traffic as well as habitual traffic congestion, as some people might choose public transportation if they were more aware of the traffic conditions [1].

The results of a study presented in [2] showed that the level of congestion depends on the complexity of the road network. The travel time for a journey along an arterial

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road is influenced not only by the road geometry, but also on the traffic flow characteristics and traffic signal coordination [3]. Compared to TTE models for freeways or arterial roads, TTE for urban network is considered more difficult for the following reasons: signal controls, network complexity (interleaving, intersections, and geometry), diversity of vehicles and the interruptions caused by incidents [4]. Vehicular flows on freeways are often treated as uninterrupted, while those on an urban network are conceivably much more complicated, since vehicles traveling on these are subject not only to queuing delays but also signal and turning delays. TTE is thus more challenging for an urban network than for freeways or single arterial roads for a number of reasons, such as the complexity and path routing problems in urban networks, the unavailability of real-time sensor data, traffic sensors coverage issue, and the lack of an ability to consider real-time events [1]. Both routing and path selection issues need to be solved if TTE is to be applied to urban networks, i.e., the TTE model has to suggest the shortest travel time path for a given origin and destination (OD) pair. Moreover, it should be remembered that TTE for urban networks is highly stochastic and time-dependent, due to random fluctuations in travel demands, interruptions caused by traffic control devices, incidents, road construction, and weather conditions [1].

The coverage and accuracy of real-time traffic information are the key factors for a successful TTE system. Most TTE systems are built-up on huge, cloud-based backend systems that deal with a huge amount of data processing and TTE computing, such as the Google Maps® service. These TTE systems operate in a request-response model in which the clients make a travel time request by sending an origin, destination, and departure time to the server, and the server responds with the estimated travel time. However, dealing with a large amount of simultaneous real-time TTE requests may lead to system overload and result in a performance bottleneck due to constraints of the computing resources that are available.

Vehicular Ad hoc Networks (VANET) represent a wireless communication technology which is capable of forming a mobile ad hoc network for moving vehicles and road side units, and this is the promising research area for ITS applications [5]. With VANET, vehicles equipped with an on-board unit (OBU) can exchange information with neighborhood vehicles via a vehicle-to-vehicle (V2V) communication or road side unit (RSU) installed at an infrastructure facility, such as the traffic signals at an intersection, thus enabling vehicle to RSU (V2R) and RSU to vehicle (R2V) communications. VANET can be applied to many vehicular applications, including vehicle collision and security distance warning, driver assistance, cooperative driving, cooperative cruise control, dissemination of road information, Internet access, [6], and eco-driving [7].

This paper proposes a novel approach for TTE and route suggestion for urban networks. Assuming that every intersection signal is equipped with a RSU, every vehicle is equipped with an OBU, and every origin as well as destination of the journeys are not far from the intersections. The main idea is that all the origins and destinations of the journeys are regarded as departing (arriving) at the intersections; that is, a journey starts from one intersection and ends at another. A real-time traffic information network can then be built up with V2R/R2V communication and the exchange of RSU-to-RSU (R2R) intersection information. Different to traditional client-to-server request-response model, this paper applies the idea of collaborative computing which solves the performance bottleneck problem in traditional model. Using real-time traffic information a RSU can respond to the travel time and routing path requests from an OBU, while also collecting real-time traffic information from this OBU, as it is embedded in the request packet.

The concept of the proposed Intersection-to-Intersection (I2I) travel time estimation and route suggestion system for urban network is illustrated in Fig. 1, which consists of three subsystems, including RSU, OBU, and cloud backend. The communication protocol is designed to facilitate system operations, which includes V2R, R2V, I2I (also known as R2R), R2C (RSU-to-Center), and C2R. The concept of collaborative intelligence is applied in the proposed model, that is, a consumer is also a contributor. Vehicles equipped with an OBU share real-time information about their journeys (traveled path, average speed of each road segment, and delays in each intersection), while it sends a TTE request to the destination to RSU, and the RSU then responds with the suggested route as well as the estimated travel time. RSU updates the traffic information collected from OBUs and then it exchanges this to the neighborhood RSUs. An efficient propagation-based data exchanged algorithm and a traffic information super-matrix data structure are designed for the R2R (RSU-to-RSU) real-time traffic information exchange. The details of the system protocol and design are discussed in Section 3. With the middle tier RSU, which coordinates between the client and backend system, the problems with regard to response time and bottlenecks that occur in a two-tiered client server system can be solved by the application of distributed computing. The backend system (center) can focus on big data analysis, historical traffic information pattern mining, finding the optimal traffic signal plans, and coordinating the RSUs for global network performance optimization. With this mechanism, RSU can dynamically adjust the signal plans to best fit the real-time traffic conditions, as collected from the OBUs.

The rest of this paper is organized as follows. A review of the literature on TTE is presented in Section 2. The architecture, protocol, and design details of the proposed I2I TTE and route suggestion system are then discussed in Section 3. Details of the related experiments and a discussion of the results are provided in Section 4. Finally, Section 5 concludes this paper and discusses some directions for future work.

2. Related works

The literature includes several studies that examine travel time prediction or estimation, but most focus on predicting the travel time on freeways [8–13] or simple arterial networks [14–16]. For example, in [11], Wang et al. applied the k-nearest neighbors (KNN) approach and a linear regression model for long freeway corridor travel time