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Mitigating flash crowd effect using connected vehicle technology

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ABSTRACT

A Flash Crowd Effect (FCE) occurs when in the case of non-recurring congestion a large portion of drivers follows similar re-routing advice. Consequently, congestion is transferred from one road to another. Coping with the FCE is challenging, especially if the congestion results from a temporary loss of capacity (e.g. due to a traffic incident). The existing route guidance systems do not address FCE, as they either do not consider the effects of guidance on the rest of the road network, or predict link travel times based on the number of vehicles travelling on the link, which in the case of the loss of capacity is unreliable. We demonstrate that the FCE can be addressed in a distributed way with Vehicle-to-Vehicle (V2V) communication provided by Connected Vehicle (CV) technology. The proposed in-vehicle TrafficEQ system provides vehicles with mixed route guidance strategy—i.e. a route is autonomously chosen by the vehicle with a probability that is inversely proportional to the latest reported travel time on the route. Real-time travel time information is crowd-sourced by TrafficEQ users. Using realistic simulations of incident-related capacity drops on a classic two-route highway example and a realistic urban road network, we demonstrate that TrafficEQ can address the FCE by reducing travel time oscillations among the alternative routes. The system's drawbacks—in particular the occasional necessity of providing incentives to follow the guidance—are discussed.

1. Introduction

Traffic Informations Systems (TISs) enable better utilisation of road networks by providing drivers with real-time information about traffic conditions and allowing them to make better routing decisions [1]. The future TISs will be enhanced with Connected Vehicle (CV) technology, allowing vehicles to create a wireless vehicular *ad hoc* network (VANET)—a cost-effective alternative to the existing traffic sensing technologies such as inductive-loop detectors. The technology provides various *ad hoc* communication patterns such as between vehicles (V2V) and between vehicles and road infrastructure (V2I) [2]. However, provision of traffic information is only the first step in dealing with congestion. The second step consists of route selection. This is a challenging task, especially in cases of unpredictable *non-recurring* congestion when traffic incidents result in temporary loss of capacity and when a strong link between routing decisions of drivers and the travel time exists (e.g. when several vehicles share the same origin-destination pairs and the number of alternative routes is limited). In the literature this is often illustrated by a two-route example, in which the main route is a two-lane highway with one lane blocked by a stalled vehicle and the second route is a bypass with a lower speed limit [3]. If everyone uses the same *pure routing strategy* (e.g. based on the shortest-time principle) combined with similar traffic information, the congestion is shifted from one road to another. In the literature this is referred to as the *Flash Crowd Effect* (FCE) [4], *similar advice problem* [5], or *overreaction* [6]. In this case real-time information about prevailing conditions can be misleading, as it does not include the delayed effect of vehicles entering the route in its associated travel time. Moreover, it is difficult to predict travel times based on the number of travelling vehicles when the road capacity unpredictably changes [6]. Research literature gives very little attention to how to cope with the FCE problem in practice. While it is noticed in [4–6]—only general indications, such that a mixed route guidance strategy should be used instead of the pure shortest-time route guidance [7]—are given. The exception—work reported by Davies in [3]—explicitly studies the problem. By using the two-route example, the authors demonstrate that the FCE can be mitigated by means of anticipation of delay which is learned over time. However, the approach of Davies is centralised. It also relies on information about the exact number of vehicles and their

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travel times on the route obtained from fixed sensors. Moreover, practical aspects of the system deployment are not addressed.

CV technology offers new tools to approach the FCE problem. Whereas most of the V2V-based TISs focus on efficient traffic information dissemination (e.g. [8–11]), route guidance is included in several V2I-based systems (e.g. [12–15]). Although these systems were not evaluated in situations where the FCE is likely to develop, they may have potential to cope with the problem via route choice coordination. However, this requires an entity dedicated to coordination (e.g. agents [12,13] or an online environment [14]). Moreover, relying on link travel time prediction (e.g. in [13]) in cases of unpredicted road capacity drops—typically found in FCE—is not trivial.

In this paper we tackle the FCE problem explicitly by proposing an alternative CV technology-based approach (in V2V mode). The proposed method, hereafter referred to as *TrafficEQ*, is fully distributed and infrastructure-less. It uses autonomous in-vehicle route guidance relying on traffic information crowd-sourced by vehicles using V2V communication. Moreover, it does not use travel time prediction or route selection coordination. Guidance provided by TrafficEQ is based on a mixed routing strategy where the probability of selecting a route is inversely proportional to its latest reported travel time. It is compared to conventional guidance based on the shortest-time principle. System evaluation is carried out using the classic two-route example and a realistic urban road network, both simulated with traffic (SUMO [16]) and network (NS-3 [17]) simulators. The main finding is that the FCE can be mitigated by combining latest travel time information crowd-sourced via V2V communication with autonomous probabilistic routing. Moreover, FCE-related time oscillations among the alternative routes are significantly reduced even if only a small portion of vehicles uses the system, while the rest applies shortest-time routing. The main drawback of TrafficEQ is that users are periodically requested to select a sub-optimal route. In the case of drivers with self-regarding preferences, our approach needs to be extended with incentives, e.g. based on the road pricing concept.

The remainder of this paper is organised into five sections. We start with a review of the literature. Section 3 introduces the TrafficEQ system. Section 4 contains the description of the simulation setup and the results of our experiments. Section 5 points out system weaknesses and future research directions. Finally, Section 6 summarises the article.

2. Related work

First we start with an overview of route guidance in the context of the FCE. Then, we discuss different traffic information architectures. Finally, guidance solutions based on CV technology are analysed.

2.1. Route guidance and FCE

Route guidance can be either (i) *centralised*—i.e. route selection is performed at some central site (as in the approach proposed by Davies [3]), (ii) *decentralised*—i.e. route selection is performed at an autonomous sub-system (as in the BeeJamA system [12]), (iii) *distributed*—i.e. route selection is performed in-vehicle (as in the proposed TrafficEQ). The advantage of centralised and decentralised guidance systems is that they allow coordinated routing decisions. However, this requires an additional traffic management component.

In general, recent work demonstrates that route guidance can improve the overall road network performance [18,19]. Several commercial TISs (e.g. TomTom [20] or Waze [21]) provide guidance relying on prediction of traffic conditions. The prediction is based on a combination of prevailing conditions and historical values [22]. However, due to low market penetration these systems do not consider the effects of guidance on the rest of the road network and future road conditions [22]. Consequently, they cannot react to the FCE. The question of how to best use traffic information in cases of non-recurring congestion, where the number of alternative paths is low and a capacity drops are observed, is much more difficult to address. While there is a consensus that route guidance based on the shortest-time principle leads to the FCE [4–7], very little attention has been devoted to how to practically solve the problem. The exception—work reported by Davies [3]—focuses on the FCE in a two-route scenario. A hypothetical system in which the route guidance is based on anticipation (the system learns the maximum number of vehicles that can travel on each route) is proposed. The authors demonstrate that characteristic oscillations in travel time among the alternative routes resulting from the FCE can be significantly reduced. The solution is implicitly based on a centralised architecture. Moreover, information about the practical implementation of the proposed approach is not given.

2.2. Centralised vs. decentralised vs. distributed traffic data management

In general, systems with centralised traffic-related data processing such as Waze or TomTom have a greater capability to predict the traffic situation. This is mainly due to the network-wide traffic awareness and collection of traffic data based on the floating cellular data method. In such systems, updates are far from real-time—lag time is typically in the range of 2 to 30 minutes [12] (although this is a system designers' choice rather than technical restriction). However, bandwidth limitation, dissemination delays, and communication costs are the main drawbacks of such systems [23,24]. These can be addressed by systems with decentralised (e.g. Claes et al. [13] and BeeJamA [12]) or distributed (e.g. TrafficEQ) traffic data management. In the former traffic awareness is provided by dedicated entities via V2I communication with vehicles, while in the latter traffic information is exchanged directly between vehicles using V2V communication. Decentralised and distributed systems can easily be extended (via V2I communications with signal controllers) with real-time Signal Phase and Timing (SPaT) information. Access to SPaT has great potential to further improve traffic efficiency [25,26] via additional speed advisory systems extending route guidance.

2.3. CV technology-based TIS approaches

Most of the CV technology-based TISs proposed in the literature focus on message dissemination (e.g. [9]) and estimation of traffic conditions (e.g [27]). In general, infrastructure-less TISs (i.e. based on V2V communication only) allow for efficient traffic information crowd-sourcing even with low penetration rates of the system [8] (for details please refer to [24]). A comparison of selected systems is given in Table 1. Some infrastructure-based TISs (i.e. relying on V2I communication) also include route guidance. For instance, the multi-agent V2I system introduced by Claes et al. [13] uses decentralised traffic data collection combined with distributed route selection. In the system vehicles send their route intentions to the infrastructure agents, which predict travel times based on the received intentions. Next, vehicles—based on the predicted travel times—select the fastest route, which might lead to the FCE. Sharing of route intentions allows partial coordination of route selection among vehicles, thus can reduce the consequences of the FCE. The BeeJamA system [12] is also based on a multi-agent V2I approach with decentralised traffic data collection, although it uses smaller sub-systems. In addition, it relies on decentralised