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Message forwarding based on vehicle trajectory history in Fully Distributed Traffic Information Systems

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ABSTRACT

Fully Distributed Traffic Information Systems (FDTIS) are based on vehicle-to-vehicle wireless data transmission that enables traffic self-organization. For instance, alert messages transmitted by vehicles in poor traffic conditions allow receivers to avoid congested roads and reduce travel time.

Such systems are of great practical interest and may provide excellent results in urban conditions due to the presence of numerous potential partners for most vehicles. Unfortunately, many applications already use the wireless transmission medium in cities, leading to frequent problems with saturation. In order to avoid such issues, FDTIS must generate as few transmissions as possible, while remaining effective. In the specific context of congestion avoidance, we present a method that improves the efficiency of traffic alert messages by directing them to the geographic regions where they are most useful. This method uses past trajectory data from the vehicles involved in a traffic jam, thus decreasing the number of messages. We compared the performance of our method in simulation to a reference implementation and showed that, in the case of intensive traffic, this method prevents saturation of the wireless medium which would have resulted in a general degradation in performance. From a macroscopic point of view, we also showed that the improvement in medium usage obtained had no impact on the ability of our system to ease traffic jams.

1. Introduction

In many countries, the development of urban, suburban or inter-urban transportation generates many traffic jams due to structural reasons or unexpected events. One possible means of combating traffic jams is to use a Personal Navigation Assistant (PNA). To allow users to reorganize their journeys, these PNA must be able to perform dynamic routing based on up-to-date data provided by a Traffic Information System (TIS). Such systems have already been proposed. The first were academic projects, e.g., Notice [1], SaveTime [2], Street Smart [3], TraffCon [4], SOTIS [5], Cartel [6], but several commercial or pseudo-free products are now available, e.g., [7,8] or [9].

Whatever the approach, vehicles require up-to-date traffic data. Thus, it is necessary to measure the current state of the traffic (*measurement*), construct a synthetic picture of this state (*aggregation*), and send this information to vehicles wishing to dynamically calculate their route (*diffusion*). Each of these three functions can be either *centralized* (i.e., performed by common equipment) or *distributed* (i.e., performed by the vehicles). In this article, we focus on systems where all the above functions are distributed, leading to the definition of Fully Distributed Traffic Information Systems (FDTIS).

FDTIS present important benefits, but also disadvantages. In dense urban environments in particular, they can contribute to the saturation of the communication medium. Litterature-proposed approaches that fight against saturation operate at different levels. They are based on an analysis of the communication channels state (medium level), the geometric relationships between the partners that communicate (geometric level) or the various specificities of the application requiring communication (applicative level). Of course, several approaches can be used simultaneously in some proposals. At the medium level, [10] have proposed ATB, an adaptive protocol in which the partners continuously observe the medium occupation in order to optimize their own transmissions. At the geometric level, [11] have proposed the UMB protocol for selecting a transmitter located near a line segment. [12] have proposed a broadcast suppression

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technique based on the distances between partners that use the same highway. In the same paper, the flow direction is also taken into account because it is important information regarding the application. Finally, [13] have presented a similar but more general solution that also uses the neighboring relationships between partners. At the applicative level, [14] have proposed an adaptive transmission method based on an evaluation of the knowledge of traffic conditions that is held by the partners in the vicinity of the emitter.

In this article, we address specifically the problem of medium saturation at the applicative level by using the information provided by vehicles stuck in traffic. For this purpose, we developed an original method that takes into account the history of vehicles to route the traffic warnings to the regions where they are the most useful.

The rest of the paper is organized as follows: the next section provides a short review of Distributed Traffic Information Systems and presents typical issues relating to wireless data transmission in this context. In Section 3, we present the cooperation model we developed to implement and evaluate the system we propose. In Section 4, we present the data routing methods already proposed for data transmission; each is analyzed in order to verify if it can be used in the context of FDTIS. In Section 5, we present the principles of the protocol proposed in this paper to route the traffic data, as well as potential implementation issues. Finally, Section 6 provides an evaluation of the performances of our routing protocol in comparison with a reference protocol.

2. Review of traffic information systems

The first Traffic Information Systems (TIS) were based entirely on Traffic Information Centers (TIC). In these systems, traffic data were collected by sensors attached to the road network. (Notice [1], TMC [15], TraffCon [4].) This information was sent to a traffic center where it was compiled and then transmitted to the end users by FM radio (RDS protocol). However, this architecture is poorly reactive and is not scalable because of instrumentation costs.

The low cost of geolocation technology (GPS) and the massive development of cellular phone networks has modified the structure of TIS because the vehicles themselves can now provide the instrumentation functionality,[2] in other words, these structures have become distributed. However, this kind of TIS is not fully distributed because it is still based on a TIC to which end-users must be connected by a cellular phone. The main interest of this architecture is to offer a global view of traffic conditions. Its other features can be seen as advantages or disadvantages, depending on your point of view. Here is a list of known disadvantages, from an end-user point of view:

- Users have to pay for both communications and traffic information services; so ironically, they have to pay for information they collect themselves.
- The toll-free systems currently available (e.g., Waze [9]) do not offer any confidentiality, they do not support any anonymization and allow the service provider broad access to the user's private life.
- The cellular phone network was not designed for continuous, massive usage, so an overload is likely to occur.
- The response time of these systems is not excellent due to delays related to the functioning of the Traffic Information Center.

This is why it makes sense to investigate distributed data transmission solutions (i.e., users can collaborate without any central mediator). For example, [16,5,3,14] and many others have studied such systems.

The advantages of Fully Distributed Traffic Information Systems (FDTIS) are the following: they are highly scalable, with no exploitation costs, and they can be very reactive when partners are physically close together. This reactivity allows traffic perturbations that have an immediate impact for users to be taken into account, as it allows them to change their trajectory very quickly. This feature is especially useful in urban contexts, where centralized traffic information systems are not fast enough.

These systems could be implemented because several low-cost wireless technologies are available (e.g., 802.11n or 802.11p) and administrations such as the National Highways Traffic Safety Administration (NHTSA) or the Department of Transportation (DOT) in the USA are currently promoting mandatory built-in vehicle-to-vehicle (V2V) communication technology for car safety [17].

However, FDTIS use a medium that does not allow global communication. This is why one must use a data routing method in order to transmit information from partner to partner. Paradoxically, this need can lead to very different constraints, depending on the situation. Indeed, when the traffic is light, the main problem will concern connectivity between vehicles. Thomin et al. [18], for example, studied this situation. Conversely, when the traffic is denser, an informational storm is likely to occur and lead to the saturation of the medium [19] because the phenomenon is exponential. Informational storms occur in regions densely populated with partners, such as urban areas. This problem may be aggravated when other types of applications also use the medium, which is especially the case if the transmission uses a popular wireless technology, such as Wi-Fi (normalized as IEEE 802.11). This is a particularly unproductive situation, as it penalizes all the users of the medium, including mission-critical safety applications.

The goal of this paper is to propose a way of minimizing the usage of the wireless medium in the context of FDTIS, even when the traffic is particularly dense.

3. The FORESEE framework

In FDTIS, the way in which the vehicles cooperate may have a huge influence on the traffic. This is why the project FORESEE aims to build an efficient cooperation model that is tested in various situations using simulations. The first results of this project can be found in [14]. This paper presents the model itself and analyzes its behavior in standard, favorable situations. In [18], we analyzed its performance in a situation of informational famine related to the initial deployment of the system. The current paper addresses the inverse situation: how to avoid an informational storm provoked by a large number of cooperating partners.

In order to make the rest of the paper more understandable, this section presents an overview of the FORESEE model. The simulator that implements this model is described in Section 6.2.

3.1. The FORESEE cooperation model

The FORESEE model is based on a fully distributed system composed of a set of agents that are physically installed in each vehicle. Each agent is part of a driving assistant that evaluates the surrounding traffic conditions from data sent by the other agents via a wireless medium. This approach is typically cooperative because each agent only uses the information received from other agents. The model is logically supported by three sub-systems, as shown in Fig. 1:

- *Measurement*: this sub-system builds a quality indicator by comparing the vehicle's current speed with the speed deemed normal for the edge of the road network corresponding to the vehicle's current position. It produces a flow of scalar traffic quality indicators (Q_s), which provide an instantaneous

[2] The traffic jams detection can be done automatically or with the help of the drivers (TomTom HD Traffic [8], Coyote [7], Waze [9], Save Time [2]).