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A distributed virtual traffic light algorithm exploiting short range V2V communications☆

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ABSTRACT

The correct and prompt definition of priorities at intersections is one of the key issues for vehicular safety and efficient traffic management. Traffic lights currently control only a limited number of intersections and increasing their number is clearly infeasible due to the high costs of deployment and maintenance. A new solution will be possible in a near future, when vehicles will be equipped with wireless technologies. Their capability of communicating and coordinating to each other will create the conditions for the implementation of a virtual traffic light (VTL) architecture, where priorities are autonomously defined by the involved vehicles. With this scenario in mind, we describe a novel VTL algorithm aiming at defining the priorities of the intersections in a distributed and controlled way. Besides the algorithm description, the main related issues are thoroughly discussed. In addition, a real implementation is detailed and the validation of the algorithm is provided. The testbed, based on the IEEE 802.11p short range wireless technology, has been reproduced in a controlled laboratory environment and in a field trial with equipped vehicles.

1. Introduction

The recent advances of wireless technologies in vehicular scenarios are bringing the paradigm of connected vehicles near to implementation. Cooperative vehicles, communicating and coordinating to each other, will increase the safety of passengers and improve the traffic management, answering to issues that are of primary importance.

Focusing on safety, the Global status report on road safety 2013 shows that 1.24 million deaths on the road were measured in 2011, a number that might increase up to 1.9 millions in 2020 if nothing is done [2]. In [3,4], it is stated that road crashes are expected to become the third cause of death by 2020. In [5], it is shown that the most frequent causes of crashes at intersections are inadequate surveillance (44.1%), followed by false assumption of others action (8.4%), turn with obstructed view (7.8%), illegal maneuver (6.8%), internal distraction (5.7%), and misjudgment of gap or excessive speed of other vehicles (5.5%). With wireless technologies helping maneuvers, most of these accidents could be avoided, and many lives saved. Based on results from a large two years experimentation made with 2800 connected vehicles, it was estimated that up to nearly 1000 lives could be saved in the USA each year, just implementing intersection movement assist and left turn assist applications [6].

The reduction of traffic congestion is also a relevant issue, causing waste of time and stress to citizens, besides an increase of air pollution [7]. To reduce congestions, an increase of the vehicular flow rates is obviously cheaper than reducing the number of vehicles or increasing the infrastructure capability [8]. In this direction, improving the management of intersections is one of the most important issues. However, the percentage of intersections that are governed by traffic lights is inevitably limited; for instance, as reported in [8], nearly 0.5% in the United States, 24% in New York, 25% in Dublin, and 16% in Porto. Significantly increasing this percentage is not realistic due to the heavy costs of deployment and maintenance. Furthermore, since traffic lights generally work under fixed or slowly varying parameterization, inefficiencies are likely under highly dynamic traffic conditions. Even more important, presently there is no interaction between traffic lights and vehicles, and all is left in the driver's hands.

1.1. Related work

Using wireless communications to improve the traffic light effectiveness has been indeed recently considered. For example, the

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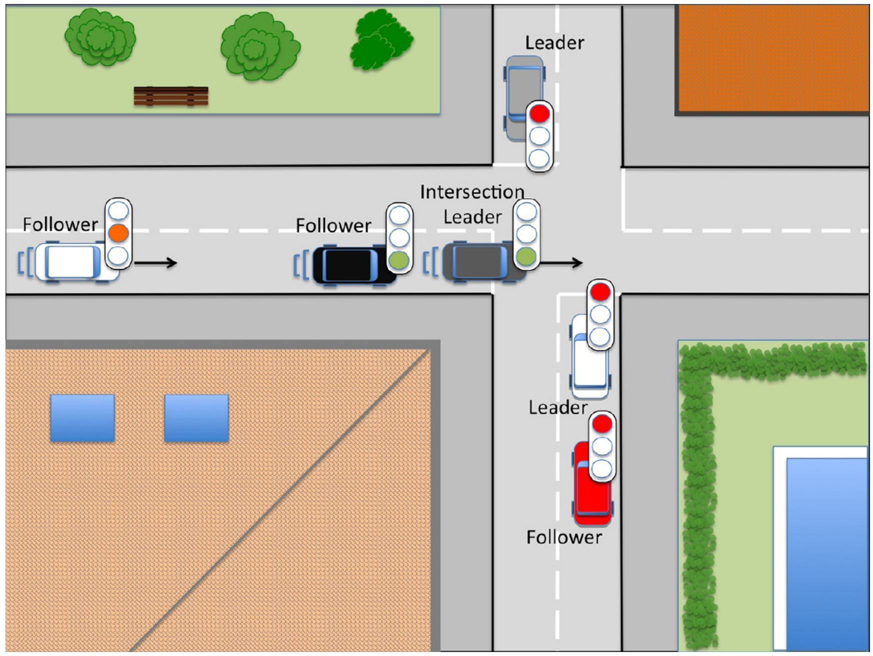

Fig. 1. Virtual traffic light example scenario.

optimization of the stopping position of vehicles to maximize their speed when the traffic light becomes green is discussed in [4], the timing pattern of traffic lights is adjusted according to traffic demand in [9], a centralized optimization of groups of traffic lights is performed in [10], and a coordination between vehicles and traffic lights to minimize the fuel consumption is proposed in [11]. All these works, however, rely on an infrastructure; thus, even if advantages are obtained, still they do not solve the problem of how to improve safety in those intersections that do not have any infrastructure.

A different approach is enabling vehicles to directly coordinate among themselves, thus implementing a virtual traffic light(VTL) [8] (Fig. 1): vehicles, hereafter called (SVs), are equipped with an on board unit(OBU) providing wireless communication capabilities to interact with each other and determine the priorities of the intersection. This can be accomplished with two different approaches (or a mix of the two): either using cellular technologies or exploiting ad hoc communications [12–14]. The former approach is interesting due to the widespread diffusion and wide coverage it grants, but could lead to a capacity limitation in the presence of huge amount of vehicular data traffic [15,16]. The alternative is to enable ad hoc communications, thus moving to the field of vehicular ad hoc networks (VANETs) [17]. Being it explicitly designed for VANETs, in such a case the most promising option is the use of IEEE 802.11p [18], that provides 10 MHz channels at a carrier frequency of approximately 5.9 GHz.

The first (and only, at the best of authors' knowledge) VTL distributed algorithm for VANETs has been described in [8], where simulation results showed up to 60% increase of the average flow rate in the reference city of Porto. The adopted algorithm is based on the definition of cluster of vehicles, cluster head, and VTL leader. The vehicles on the same road form a cluster and the one which is nearer to the intersection is the cluster head; the cluster head which is farther from the intersection is then elected as VTL leader, which will be responsible to determine the priorities and broadcast the virtual traffic light messages. As soon as the VTL leader leaves the intersection, a new VTL leader is elected. The same algorithm has been recalled in many following works, evaluating the pollution reduction [19], discussing the graphical user interface(GUI) [20], and addressing the feasibility in non line of sight(NLOS) propagation conditions [21].

One of the key-aspects of the algorithm in [8] is the use of broadcast messages sent by the VTL leader; since broadcast messages do not adopt any acknowledgement mechanism, there is no possibility to check the correct reception of the messages, thus possibly causing safety critical situations.

1.2. Objective and outline

In this paper, we propose a novel VTL distributed algorithm based on short range wireless communications, where the exchange of information between SVs occurs using both broadcast messages for signalling and unicast messages for precedence definition and traffic light decisions. The algorithm has been designed for those intersections where the deployment of a traffic light is not cost-effective; based on the first coming, first crossing principle for the initial coordination, it exploits a grant transfer mechanism to minimize the network load and guarantee that the intersection is crossed safely. The algorithm has been implemented and tested through low cost IEEE 802.11p devices, using open source software. To the best of our knowledge, this is the first time a VTL algorithm has been implemented using IEEE 802.11p devices. Besides tests performed in our laboratory, adopting virtual coordinates to set the position of the SVs, a scaled field trial with equipped vehicles has been implemented to test the application.

The rest of the paper is organized as follows: The algorithm is detailed in Section 2 and the main related issues are explored in Section 3; in Section 4, the testbed we implemented to validate the algorithm is shown, with examples obtained both in laboratory with virtual coordinates and on field; A comparison with the other VTL algorithms and possible improvements are then discussed in Section 5; Finally, in Section 6 our conclusion is drawn.

2. The virtual traffic light algorithm

2.1. Assumptions and summary of the algorithm

Basic idea. The designed algorithm is intended for those intersections where the deployment of a traffic light is not cost-