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An auxiliary V2I network for road transport and dynamic environments

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ABSTRACT

Since vehicle-to-infrastructure (V2I) communications require a major initial outlay and continuous maintenance, they have been less frequently implemented than vehicle-to-vehicle (V2V) communications in applications in the field of Intelligent Transportation Systems (ITS). Nevertheless, making use of the information provided by the infrastructure – traffic signals, traffic panels, and so on – can help improve the performance of various ITS applications. The present work describes the design and implementation of a low-cost infrastructure network based on ZigBee technology to alert drivers (or even override them by using active safety systems) in the case of some unexpected circumstance on the road so that they can prepare for the appropriate handling of their vehicles. Its implementation as an auxiliary network within a larger communications scheme allows the network's load to be reduced and its performance to be improved. The proposed architecture was tested on a real car in a real scenario with quantified results for different applications.

1. Introduction

The number of vehicles on the roads has long been steadily increasing worldwide. Just in the EU27, the number of passenger cars (vehicles designed to seat no more than nine persons, including the driver) grew by 12.77% – around 26 million cars – between 2000 and 2006. Despite this growth, the annual road accident deaths decreased in the same time interval by around 23% (EUROSTAT, 2010), indicating that both vehicles and roads are becoming safer.

The first safety systems developed for road vehicles were such passive systems as seat belts and airbags that operate when a critical situation occurs, e.g., when a crash is unavoidable. Later, with the introduction of the Anti-lock Braking System (ABS) which reduces braking distances on slippery surfaces, researchers and manufacturers made the first major step towards Advanced Driver Assistance Systems (ADAS) designed to aid drivers during driving. Commercial vehicles today incorporate several safety-oriented ADAS solutions which can either alert drivers to hazardous scenarios or act on the vehicle if the driver is distracted. Two examples are the Lane Keeping (LK) system available on Mercedes S and E Classes which causes the steering wheel to vibrate when the vehicle detects that it is leaving its lane unintentionally, and the more recent *City Safety* system developed by Volvo and incorporated into their XC60 model which, at speeds slower than 20 km/h, is able to stop the vehicle when it detects some obstacle in front, the aim being to reduce the number of rear-end collisions in urban environments.

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Despite these encouraging advances, the information obtained via on-board sensors is insufficient in itself for the detection of potential risk situations. In this sense, one of the most challenging lines of research in the ITS arena is the development of communications technologies for ADAS systems based on inter-vehicular cooperation. Recent years have seen the design of the first architectures for this purpose. In 2003, the United States Department Of Transportation (US DOT) launched the Vehicle Infrastructure Integration initiative (VII) with the vision of using Dedicated Short-Range Communications (DSRC) between vehicles in order to achieve improvements in safety and mobility (U.S. DOT, 2010). As a result of this initiative, the Federal Communications Commission (FCC) reserved a frequency band at 5.9 GHz for transportation safety and mobility applications. Subsequently, the IEEE created standards IEEE 1609 and IEEE 802.11p to define a basic architecture for Wireless Access in Vehicular Environments (WAVE). The WAVE architecture comprises three basic elements: (i) the On-Board Unit (OBU), designed to be installed in vehicles and to guarantee connectivity while moving; (ii) the Road-Side Unit (RSU), designed to be installed in such road elements as traffic lights and signals; and (iii) the service channels to allow bidirectional V2V or V2I connectivity (Uzcategui and Acosta-Marum, 2009). In 2009, after six years of research, the US DOT decided to rebrand VII as the IntelliDrive initiative, the purpose being to study the application of other wireless technologies for mobility applications while keeping DSRC for safety applications (U.S. DOT, 2010).

At the same time, the International Standards Organization (ISO) defined an architecture for V2V and V2I communications known as CALM (first Communication Air-interface, Long and Medium range but later re-branded as Communication Access for Land Mobile) which allows permanent V2x communications through various wireless technologies such as 2G/3G cellular networks, infra-red, WiFi (IEEE 802.11 a/b/g), WAVE, and microwaves, among others (Toulminet et al., 2008; Williams, 2003). This architecture has been implemented in the Cooperative Vehicle-Infrastructure Systems project (CVIS), and the results of mid-project experiments have already demonstrated the viability of its implementation (Ernst et al., 2009).

So far, the use of communications systems has extended the ADAS development scope, allowing to face more complex scenarios. Collision Warning Systems (CWS), Collision Avoidance Systems (CAS) and Cooperative Adaptive Cruise Control (CACC) are some examples of applications which take advantage of the shared information among vehicles (Sengupta et al., 2006; Milanés et al., 2010d, 2012a; Rajamani et al., 2000). Nevertheless, most of these applications focus on completely automated vehicles, neglecting the potential of the infrastructure. On the other hand, the Advanced Traffic Management Systems (ATMS) make use of the infrastructure information to manage the traffic flow, minimising traffic jams on highways, at intersections, and at merging points (De Schutter et al., 1999; Koller et al., 1994). To that end, the ATMS control different infrastructure elements such as traffic signals, traffic lights, dynamic information panels; based on the incoming information from sensors installed as part of the infrastructure – e.g., electromagnetic loops, cameras, radars. It is clear that, with a solid V2I communications architecture such as CALM, the two sets of applications – ADAS and ATMS – could be perfectly merged, allowing a central system to combine the information coming from vehicles and from the infrastructure in order to improve road safety and traffic efficiency.

This paper deals with the communications architecture developed by the AUTOPIA program, a Spanish research group focused on autonomous driving. The final goal of this program is to create a reliable communications network where information exchanges among all the present agents – i.e. vehicles, traffic lights, traffic signals and pedestrians – leading to a safer traffic system. In this sense, there are some previous results that are worthy to highlight as the cooperative adaptive cruise control based on V2V communications (Milanés et al., 2012a) and the V2I-based management system for complex traffic situations as merging or intersections (Milanés et al., 2011, 2012b).

Continuing with this line, the present work focuses on the integration of infrastructure information into the existing scheme, with the goal of increasing the amount of data available for controlling the vehicles inside an urban area. To that end, the inclusion of an auxiliary layer into the communications architecture is proposed. This layer will be composed of several road units, which will constantly send relevant information to the nearby vehicles, acting as road beacons. The implementation of the auxiliary layer has been done using ZigBee technology, due to the low-cost and low-power consumption of the devices.

In brief, the following issues will be addressed in the present communication:

- Design of an auxiliary network to be embedded into the current architecture.
- Implementation of the new layer using ZigBee devices, which will require stretch the limits of the technology for an application which it was not intended.
- Validation of the new communication scheme through different applications: (i) information alerts concerning nearby road incidents and (ii) on-demand traffic light control for priority vehicles.

The rest of the paper is organised as follows. Section 2 introduces the AUTOPIA program and its traffic control scheme. Section 3 describes the design and implementation of the secondary layer and Section 4 presents the test platform and the results of the experiments demonstrating irs functionality. Finally, Section 5 presents the concluding remarks and future work.

2. AUTOPIA’s traffic control scheme

Beginning in 1998, the AUTOPIA program has been conducting research into autonomous vehicles, its main goal being the development of a control architecture capable of emulating how a human drives a car. The program currently has a fleet of