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Reverse back-off mechanism for safety vehicular ad hoc networks

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ABSTRACT

Vehicular ad hoc networks can play an important role in enhancing transportation efficiency and improving road safety. Therefore, direct vehicle-to-vehicle communications are considered as one of the main building blocks of a future Intelligent Transportation System. The success and availability of IEEE 802.11 radios made this technology the most probable choice for the medium access control layer in vehicular networks. However, IEEE 802.11 was originally designed in a wireless local area network context and it is not optimised for a dynamic, ad hoc vehicular scenario. In this paper, we investigate the compatibility of the IEEE 802.11 medium access control protocol with the requirements of safety vehicular applications. As the protocols in this family are well-known for their scalability problems, we are especially interested in high density scenarios, quite frequent on today's roads. Using an analytical framework, we study the performance of the back-off mechanism and the role of the contention window on the control channel of a vehicular network. Based on these findings, we propose a reverse back-off mechanism, specifically designed with road safety applications in mind. Extensive simulations are carried out to prove the efficiency of the proposed enhancement scheme and to better understand the characteristics of vehicular communications.

1. Introduction

Despite the efforts invested by the automotive industry in the design of on-board safety systems, traffic accidents remain the number one cause of death in the age group between 1 and 44 in both Europe and the United States [1]. This is mainly due to the fact that, until recently, these safety systems took a reactive approach, trying to reduce the consequences, but not the number of road accidents.

Direct vehicle-to-vehicle (V2V) communications promise to open up an entire class of proactive approaches in the transportation world, becoming a very interesting research topic in both industry and academia. This interest was further increased by the October 1999 US Federal Communications Commission's (FCC) decision to allocate 75 MHz of spectrum in the 5.9 GHz band for Intelligent Transportation Systems (ITS) uses. In 2008, the European Commission also assigned 30 MHz of spectrum in the same band for ITS purposes (with a possible extension to 50 MHz).

More than a decade after the FCC's decision, the automotive industry seems to be ready for the next step: adding wireless communications capabilities inside vehicles and creating a vehicular ad hoc network (VANET) with the role of enhancing road safety.

The maturity and availability of IEEE 802.11 compliant products meant this technology was the logical choice for the medium access control (MAC) and physical (PHY) layers in VANET. Soon after the 1999 FCC decision, the American Society for Testing Materials (ASTM) took up the task of developing a communication standard for direct

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short-range communications (DSRC) in the 5.9 GHz band, based on the already successful IEEE 802.11a standard. In 2004, the IEEE decided to improve the ASTM standard and integrate it in a wider architecture for Wireless Access in Vehicular Environments (WAVE), and created the 802.11 Task Group p (TGp) to this effect. TGp reached its goal in July 2010, when the IEEE 802.11p amendment was published [2].

However, a solution based on IEEE 802.11 also has its contesters, especially because of the scalability problems that characterise the protocols from this family in ad hoc scenarios [3]. As a consequence, in its European ITS Communication Architecture [4], the ETSI adopted IEEE 802.11p at the MAC layer, but also left the door open for evolutions of the standard, or even for other technologies.

The main problem stems from the fact that the IEEE 802.11 standard has been designed with a wireless local area network (WLAN) context in mind, and it struggles to cope with the challenges of ad hoc communications. Moreover, the vehicular environment raises unique challenges, and therefore the protocol needs to cope with variable node density, important mobility, high relative speeds, driver privacy and a communication range of up to 1 km, all of this while being used by applications with an important impact on human lives.

The broadcast nature of vehicular safety communications is another issue affecting the performance of IEEE 802.11p in a VANET. Broadcast messages receive a special treatment by the Distributed Coordination Function (DCF) that provides medium sharing in IEEE 802.11, as they are not acknowledged and do not use the Request-to-Send (RTS) and Clear-to-Send (CTS) messages. This further increases the scalability problem, as the DCF is practically stripped from all the mechanisms related to congestion control, to a basic Carrier Sense Multiple Access (CSMA) scheme.

The standardisation bodies acknowledged this problem, and the ETSI released a set of technical specifications focused on decentralised congestion control for ITS operating in the 5 GHz band [5]. This framework proposes three different mechanisms for congestion control: beaconing frequency adjustment, adaptive data rate, and transmission power control. These are generic solutions, that could work for any MAC protocol, and they are not specifically designed with IEEE 802.11 in mind.

In this paper, we study the impact of the contention window (*CW*), used by the IEEE 802.11 back-off mechanism, under different values of vehicular density. This is a parameter well-known for its central role in congestion control in WLANs [6], but slightly neglected in V2V scenarios. We begin by providing a theoretical analysis of IEEE 802.11 in a vehicular context. This allows us to distinguish important characteristics of the safety messages, and compare the performance of the MAC layer using different sets of parameters. With these properties in mind, we propose a new back-off mechanism for safety VANETs, *the reverse back-off mechanism*, and we study its performance through extensive simulations.

Our main contributions can be therefore divided in two groups:

- We propose an analytical framework that accurately models the behaviour of an IEEE 802.11-based MAC protocol in a vehicular network. We show that the broadcast and periodic nature of the safety messages have an important impact on the optimal value of the contention window. We study the relationship between vehicular density and *CW* and we find that it is different from the dependence exhibited by a classical WLAN scenario.
- Based on these findings, we propose the reverse back-off mechanism. In this approach, the contention window adaptation is no longer based on collided messages, but on the expiration of periodic safety messages. We use a realistic simulation framework to study this solution from the perspective of different metrics. We also discuss the different reasons for a lost message in a vehicular environment, and show that the reverse back-off mechanism does not only increase the reception probability, but also strongly modifies the loss distribution in a positive way for safety applications.

The remainder of this paper is organised as follows. Section 2 presents background information on vehicular safety communications, VANET congestion control, and contention window adaptation in IEEE 802.11. Section 3 gives the details of the analytical model and discusses numerical results for a high density vehicular network. The reverse back-off mechanism is described in Section 4, while its evaluation makes the object of Section 5. Finally, Section 6 concludes the paper.

2. Background

This section discusses the special characteristics of vehicular safety communications, as specified by the standardisation bodies. It also highlights previous work in the area of congestion control in vehicular networks and regarding possible adaptations of the contention window in IEEE 802.11.

2.1. Vehicular safety communications

In both Europe and US, the spectrum allocated for vehicular communications has been divided in 10 MHz channels. From these channels, one is known as the *control channel* (CCH) and it is used solely by road safety applications. The rest of the channels, called *service channels* (SCH) can be used by both safety and non-safety applications. In this paper, we address medium access control using IEEE 802.11p on the control channel, therefore we are only interested in safety scenarios.

The number of proposed vehicular safety applications that could use direct V2V communication is impressive [7]. However, at a close inspection, it can be noticed that all these applications practically use the same information, coming from on-board sensors of neighbouring vehicles: speed, acceleration, steering angle, location, etc.

Considering this, the standardisation bodies decided to add a supplementary layer between the applications and the transport protocol. The role of this layer, called *message*