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Vehicular networks using the IEEE 802.11p standard: An experimental analysis

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ABSTRACT

The IEEE 802.11 working group proposed a standard for the physical and medium access control layers of vehicular networks called 802.11p. In this paper we report experimental results obtained from communication between vehicles using 802.11p in a real scenario. The main motivation is the lack of studies in the literature with performance data obtained from off-the-shelf 801.11p devices. Our study characterizes the typical conditions of an 802.11p point-to-point communication. Such a study serves as a reference for more refined simulation models or to motivate enhancements in the PHY/MAC layers. Field tests were carried out varying the vehicle's speed between 20 and 60 km/h and the packet length between 150 and 1460 bytes, in order to characterize the range, throughput, latency, jitter and packet delivery rates of 802.11p links. It was observed that communication with vehicles in motion is unstable sometimes. However, it was possible to transfer data at distances over 300 m, with data rates sometimes exceeding 8 Mbit/s.

1. Introduction

Vehicular networks, also known as *VANETs* (*Vehicular Ad hoc NETworks*) or VAN (*Vehicle Area Networks*), are composed by vehicles as well as access points located at the edges of the roads [1,2]. Such networks allow several applications, such as traffic safety, driver assistance and entertainment for passengers [3]. The constant movement of vehicles at varying speeds causes constant changes in the network topology. Further, vehicles have a limited time to exchange data among other vehicles or the access points. Therefore, it is necessary to employ protocols developed to take full advantage of the contacts between vehicles and the infrastructure [2].

IEEE proposed a family of standards for vehicular networks called WAVE (*Wireless Access in the Vehicular Environment*). WAVE is composed by two categories of standards: (i) 802.11p for PHY and MAC layers and (ii) IEEE 1609 for security, network management as well as other aspects of VANETs. Since those standards are fairly recent, most experimental research on VANETs has employed traditional 802.11 radios [4–7]. These radios, however, are not appropriate for vehicular networks, because they have a long association time [8], and communication is unstable due to the high rate of data losses [9]. Recently, some works performed field experiments with 802.11p [10–12], however those studies did not measure important link metrics such as jitter and the association time.

Existing related works focus primarily on the analysis of the throughput or loss rate, which are important to entertainment applications, however driver assistance and safety applications depend on another set of link metrics. In driver safety applications, for example in the case of collision warning, the communication must present low delivery delay and high delivery rate, while throughput is secondary. For driver assistance, for example for the formation of convoys [13], data must arrive with predictable jitter and delays, in order to ensure timely control decisions.

This paper presents field experiments using IEEE 802.11p, which focus on the link metrics important for driver assistance and safety. We measure performance metrics such as throughput, delay, jitter, loss rate and association time. To the best of our knowledge, this is the first study that evaluates the association time and jitter in field experiments with moving vehicles. The data results of this paper will help improve future studies on VANETs. With this information, more reliable simulations can be carried out, contributing to the evaluation of the feasibility of applications, services and

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protocols proposed for vehicular networks. Further, those results can be used to motivate refinements in the 802.11p and WAVE standards.

The remainder of this paper is organized as follows. Section 2 discusses the types of applications proposed for VANETs, highlighting the importance of vehicle safety applications and how the metrics evaluated in this work will contribute to the development of these applications. Section 3 presents the IEEE 802.11p protocol. The related works are presented in Section 4. The methodology of the experiments and results are described in Sections 5 and 6, respectively. Section 7 concludes the paper.

2. Vehicular networks

Vehicular networks have two distinct classes of applications, which are driver assistance and vehicle safety, and onboard entertainment applications. These classes require different QoS characteristics, due to their different communication patters, which are described below.

Applications for vehicle safety and driver assistance are intended for vehicles that exchange messages among themselves, in order to identify dangerous situations or events that may occur in the vicinity. When a safety alert is received, the vehicle warns the driver through sound or light indications, giving him/her enough time to react and avoid an accident. Examples of alerts are sudden braking, skidding vehicles and vehicles in collision course [2]. Other situations may arise as well, for example the creation of convoys, where the leader vehicle defines the route taken by several cars behind him [13]. Vehicle-to-vehicle communication is employed, in this case, to provide inputs for intelligent driving algorithms, in order to maintain the distance, speed and trajectory according to those defined by the leader. Those applications are characterized by small messages, intended for vehicles which are close to the sender, and must be received as soon as possible to avoid an accident. Thus, those communications will occur among vehicles, through a transport protocol based on datagrams, such as UDP. Such applications do not require large bandwidth, instead depending on low latency, jitter and loss rates.

The second class of application involves on-board entertainment, providing weather forecast, Internet access, television and radio streaming, among other features. These applications require a connection with a metropolitan area network, through 3G/4G or by relaying messages using the access points installed at the edge of the tracks, which are called *RoadSide Units* (RSUs). Since such communications are more time consuming and typically involve larger amounts of data than driver safety and driver assistance applications, they tend to employ connection-based protocols, such as TCP. In these applications, the throughput and jitter are key QoS metrics.

Entertainment applications can be implemented at low cost with widespread telecommunication technologies, such as 3G and 4G networks, or by using existing personal devices such as cell phones and tablets. Meanwhile, the innovative applications on VANETs are the applications related to driver assistance and safety. Those applications should not rely on 3G/4G networks, since they should operate even in situations where there is little to no network coverage due to the lack of pre-existent communication infrastructure. Further, in order to reduce the end-to-end delay, those messages should be exchanged from vehicle to vehicle, without requiring to pass through fixed infrastructure. Thus, new communication standards intended for VANETs were developed.

3. The IEEE 802.11p standard

Several initiatives have been developed in order to standardize and optimize the communication between vehicles. In 1999, the FCC allocated 75 MHz in the 5.9 GHz band for DSRC (*Dedicated Short Range Communications*) in VANETs [8]. In 2010, the 802.11 group finished the 802.11p standard which describes the communication in VANETs. The 802.11p standardizes the physical layer as well as the medium access control protocols [14]. Meanwhile, the WAVE standards define the message formats, the allocation of channels for each kind of application, as well as management and security aspects.

The main modifications in 802.11p, when compared with the traditional 802.11 are described as follows [8]. In the MAC layer, the overhead to establish a communication was reduced, due to the reduced time of contact between vehicles. In traditional 802.11, devices connected through an access point define a group called IBSS (*Independent Basic Service Set*), which must be identified when a connection is established. On the other hand, 802.11p defines a new type of BSS called WBSS (WAVE BSS), which has a fixed identifier and transmits beacons on demand. A beacon contains the essential information to establish a communication, as well as the list of services offered by the group, eliminating the authentication process. Finally, in order to eliminate the need of scanning the channels in order to find the desired network, the functions of each channel are fixed.

The spectrum band reserved for 802.11p is divided into seven 10 MHz channels, numbered between 172 and 184. Channel 178 is intended for control information, and is restricted to security applications [15]. The other channels are allocated for data transmission from different services. There are also two channels dedicated to critical applications such as life safety and public safety. The physical layer is based on the 802.11a standard and uses OFDM (*Orthogonal Frequency-Division Multiplexing*) modulation. The bandwidth was changed from 20 MHz to 10 MHz [9] in order to reduce the spreading delay (*Root Mean Square delay spread*) in VANETs. Optionally, the bandwidth can be set at 5 MHz. Also, performance improvements reduce the amount of losses caused by the interference between adjacent channels. The standard provides communication at theoretical distances of up to 1000 m, both in V2V (Vehicle-to-Vehicle) and V2I (Vehicle-to-Infrastructure) modes, with absolute and relative speeds up to 30 m/s (108 km/h) in several environments (rural, highway, urban). With 10 MHz bandwidth channels, the expected bitrate is between 3 and 27 Mbps, whereas with 5 MHz or 20 MHz bandwidth channels the maximum bitrate is 13.5 Mbps and 54 Mbps, respectively.

4. Related work

Since IEEE 802.11p is a recent standard, most existing works in vehicular network employ traditional 802.11 (802.11a/b/g/n) transceivers. In [16], a set of cars equipped with IEEE 802.11b cards with external antennas communicated with an access point. The car speeds ranged between 80 and 180 km/h. The authors showed that the bitrate is low for distances above 250 m, with 1250 byte frames. On the other hand, the bitrate reaches about 4 Mbps regardless of the vehicle's speed. Bychkovsky et al. [6] performed tests with nine vehicles, which were observed for almost one year. The cars were connected to different open access points and transferred data to a specific destination. The maximum bitrate measured in TCP connections was approximately 700 kbps. In [7], performance data was collected using 802.11a/g devices.

Balasubramanian et al. investigated the effects of WiFi handoffs on VANETs, and proposed a set of enhancements [4]. The authors conducted tests in two different cities of the United States. In the first city, a network *VanLAN* was created, composed of eleven access points and two vehicles at 40 km/h. On the other hand, in the second city, a network named *DieselNet* was created, and was composed of 24 access points. The authors showed that such networks can handle handoffs, with close to ideal performance in