Ad Hoc Networks 37 (2016) 499–511

Contents lists available at ScienceDirect

Ad Hoc Networks

journal homepage: www.elsevier.com/locate/adhoc

Light commodity devices for building vehicular ad hoc networks: An experimental study

Jamal Toutouh [a,*], Enrique Alba [a,b]

[a] Departamento de Lenguajes y Ciencias de la Computación, Universidad de Málaga, Málaga, Spain
[b] VSB-Technical University of Ostrava, Ostrava, Czech Republic

ARTICLE INFO

Article history:
Received 14 July 2014
Revised 10 September 2015
Accepted 15 September 2015
Available online 13 October 2015

Keywords:
Vehicular networks
VANET
Real world testbed
Performance analysis
Smartphones
Tablets

ABSTRACT

Vehicular communication networks represent both an opportunity and a challenge for providing smart mobility services by using a hybrid solution that relies on cellular connectivity and short range communications. The evaluation of this kind of network is overwhelmingly carried out in the present literature with simulations. However, the degree of realism of the results obtained is limited because simulations simplify real world interactions too much in many cases. In this article, we define an outdoor testbed to evaluate the performance of short range vehicular communications by using real world personal portable devices (smartphones, tablets, and laptops), two different PHY standards (IEEE 802.11g and IEEE 802.11a), and vehicles. Our test results on the 2.4 GHz band show that smartphones can be used to communicate vehicles within a range up to 75 m, while tablets can attain up to 125 m in mobility conditions. Moreover, we observe that vehicles equipped with laptops exchange multimedia information with nodes located further than 150 m. The communications on the 5 GHz band achieved an effective transmission range of up to 100 m. This, together with the optimization of the protocols used, could take our commodity lightweight devices to a new realm of use in the next generation of ad hoc mobility communications for moving through the city.

1. Introduction

Today, the longstanding promise of deploying applications to improve efficiency and safety in road transport is becoming a reality. A number of *smart mobility* solutions based on Intelligent Transport Systems (ITS) provide road users with information of traffic conditions by using wireless communication. This information is generally delivered to in-vehicle navigation systems via FM radio broadcast by using the Traffic Message Channel (TMC) or via digital media by using the Transport Protocol Experts Group (TPEG) [1]. New applications for smartphones and tablets may also receive this information via 3G or Long Term Evolution (LTE, 4G) cellular networks.

However, there are several drawbacks to most of these services [2]: (i) they are centralized and based on a fixed and costly infrastructure, e.g., over-roadway and in-roadway sensors; (ii) such systems only provide traffic information about the main roads in the city; and (iii) the information updates are in the range of 20–50 min, far from ideal real-time.

Over the last decade, the research community, the industry, and the authorities have been working on the deployment of vehicular ad hoc networks (VANETs). The idea is to equip vehicles with devices with wireless capabilities, such as dedicated on-board units or general-purpose smartphones and tablets, that allow short range communications to deploy volatile wireless networks on the roads. Thus, vehicles, as VANET nodes, may exchange useful traffic information to each other by using vehicle-to-vehicle

* Corresponding author. Tel.: +34 952 133303.
E-mail addresses: jamal@lcc.uma.es (J. Toutouh), eat@lcc.uma.es (E. Alba).

http://dx.doi.org/10.1016/j.adhoc.2015.09.013
1570-8705/© 2015 Published by Elsevier B.V.

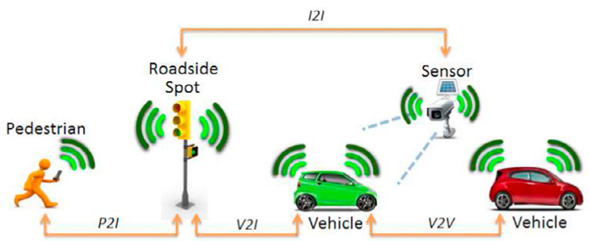

Fig. 1. Communication scheme between nodes in a VANET.

(V2V) communications. In turn, infrastructure elements, i.e., traffic lights, traffic signs, information panels, etc., with wireless communication capabilities are other types of VANET nodes that communicate with vehicles by using vehicle-to-infrastructure (V2I) communications. Recently, the whole system has been extended to include personal pedestrian devices (P2I) as VANET nodes (see Fig. 1).

VANET technologies represent an opportunity to improve ITS services and applications by using short range communications. The main advantages of using VANETs are that (1) they are decentralized and totally distributed networks, (2) the vehicles are equipped with sensors that generate and update data about all roads visited, and (3) the information received can be fully personalized according to the user. However, it should be taken into account that VANET's performance is highly dependent on its market penetration. The more vehicles in the VANETs (distributed over more roads), the better the service they provide (more information and more updates).

Currently, much of the research effort is focused on defining the most appropriate architecture for vehicular networks (radio technologies, protocols, etc.) and on developing the promising ITS services to achieve smart mobility [3]. This research has resulted in three major architectures for vehicular communications: CALM (communications access for land mobiles) proposed by the International Standard Organization (ISO) [4], WAVE (wireless access in vehicular environments) produced by the Institute of Electrical and Electronic Engineers (IEEE) [5], and ITS-5G fostered by the European Telecommunications Standards Institute (ETSI) [6]. An important issue in this kind of research is the accurate evaluation of the solutions produced. As in most network environments, modelers, simulators, emulators, and application-dependent implementations are used for this purpose.

Modelers and simulators rely on mathematical formulas to determine the behavior of network protocols and applications. These analytic methods are limited by the complexity and dimension of real world systems, which usually require simplifications and approximations that generally lead to greater differences between their results and real world behavior. Emulators mimic the entire functionality of other systems (hardware, software, and network activity), accepting the same data, executing the same programs, and achieving similar results as the system being imitated. In the literature, the majority of the tools used to evaluate VANETs are a kind of modeler or simulator [7,8].

As a useful complement (or even realistic substitute) for simulations we can use experimental real testbeds. Testbeds have important advantages with respect to the aforementioned approaches because the test can be carried out in a real world environment offering close-to-real or real performance, as well as revealing behavioral issues [9]. However, there is a lack of scientific articles that use outdoor experiments in the field of vehicular networks. The main reasons for this may be the unavailability of resources (vehicles and road equipment), the difficulties in doing field studies, and the accuracy of the performance analysis.

In the present article, we carry out a set of outdoor experiments to analyze VANET communications. The idea is to prove the feasibility of VANET short range communications when using smartphones, tablets, and laptops. Moreover, we analyze other kinds of characteristics of these devices that are useful for VANET applications, e.g., the human machine interface (HMI) provided. In this article we do not intend to define a platform for vehicular communications different from the ones proposed by the ISO or the ETSI. Instead, we want to analyze the possibility of using such widespread lightweight commodity devices to provide ITS services to improve road transport in nowadays scenarios, where specific VANET devices are not available to most road users. The main goals of our work are therefore:

- Analyzing the main features that personal mobile devices provide for deploying VANETs without having to acquire new equipment for vehicles.
- Defining an outdoor testbed in an urban area to evaluate vehicle wireless communications.
- Studying the wireless capabilities of the devices analyzed in order to discuss their use in the deployment of VANETs.

The remainder of the paper is organized as follows. Section 2 reviews the literature in VANET communications analysis. Section 3 presents the three types of devices analyzed in this work. Section 4 provides the details about the urban VANET testbed definition and experimental settings. Section 5 shows the results and discusses the performance observed in the experimentation. Finally, conclusions and future work are presented in Section 6.

2. Related work

In the last decade, a number of research projects managed by governmental, academic, and industrial entities, such as CARLINK [10], Cooperative Vehicle-Infrastructure Systems (CVIS) [11], SAFESPOT Integrated [12], DRIVE C2X [13], and PRESERVE [14], have been pushing to enhance the advanced driver assistance systems (ADAS) to provide cooperative road traffic solutions. In turn, the main international standardization institutes are involved in the specification of common frameworks and architectures for vehicular communications. The main initiatives proposed are the following: CALM by the ISO, WAVE by the IEEE, and C2C-CC (Car-to-Car Communication Consortium) [15] and ITS-5G by the ETSI.

The evaluation of the different approaches (radio technologies, protocols, and network models) to deploy vehicular networks is a major concern in this research field. In the literature, most studies aimed at this task have applied simulators and modelers. The authors have used three different types of strategies to simulate VANETs: utilizing a well-known network simulator, such as Ns-2/Ns-3 [7] or OPNET [16], that allows users to define the movement of the