Journal of Systems Architecture 59 (2013) 996–1004

Contents lists available at ScienceDirect

Journal of Systems Architecture

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

How to build vehicular ad-hoc networks on smartphones

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ARTICLE INFO

Article history:
Available online 4 September 2013

Keywords:
Vehicular ad-hoc network
Mobile application
Self-organization
Traffic congestion
Parking space

ABSTRACT

Vehicular ad-hoc networks have been defined in the literature as communications networks that allow disseminating information among vehicles to help to reduce traffic accidents and congestions. The practical deployment of such networks has been delayed mainly due to economic and technical issues. This paper describes a new software application to detect traffic incidents and exchange information about them, using only smartphones, without any central authority or additional equipment. Both road safety and communication security have been taken into account in the application design. On the one hand, the interface has been designed to avoid distractions while driving because it operates automatically and independently of the driver, through voice prompts. On the other hand, communication security, which is essential in critical wireless networks, is provided through the protection of attributes such as authenticity, privacy, integrity and non-repudiation. All this is achieved without increasing the price of vehicles and without requiring the integration of new devices neither in vehicles nor on roads. The only prerequisite is to have a smartphone equipped with Wi-Fi connectivity and GPS location in each vehicle. The proposed application has been successfully validated both in large-scale NS-2 simulations and in small-scale real tests to detect traffic congestions and empty parking spaces.

1. Introduction

Vehicular Ad-hoc NETworks (VANETs) are a form of Mobile Ad-hoc NETworks (MANETs) that provide the infrastructure for developing new systems to improve safety and comfort of driving. VANETs are generally considered formed by mobile nodes corresponding to On Board Units (OBUs) in vehicles, and stationary nodes called Road Side Units (RSUs) in the infrastructure of the road. Many efforts are being made to define new standards for services and interfaces of VANETs. In [11] the architecture called Wireless Access in Vehicular Environment (WAVE) based on the IEEE 802.11p and the IEEE 1609 standards was published. However, to the best of our knowledge, no large-scale real deployment of such a standard has been performed yet.

Currently, there are several research projects on VANETs [26], and many enterprises are developing different services, which VANETs could solve if they were already deployed. Among the potential applications of VANETs, the most remarkable one is the dissemination of traffic congestion information and collision warnings, but that is not the only one. Many others exist such as parking availability notification, vehicle tracking, weather information, advertising and Internet provision.

Dissemination of traffic congestion information is regarded as one of the most important applications of VANETs because the number of traffic congestions increases as the number of vehicles grows. Apart from negative effects on economy, traffic congestions produce high levels of stress in people and are the major cause of air pollution. It has been shown that people caught in traffic are three times more likely to have a heart attack than those who are not stuck in a congestion. Communication among vehicles could help to prevent this problem by reducing traffic congestions, what would also avoid enormous wastes of time, money, and resources.

This paper describes VAiPho, a secure communication system for spontaneous and self-organized vehicular networks based on smartphones with GPS and Wi-Fi connectivity, which does not require any infrastructure in vehicles or on roads because its operating mode is completely distributed and decentralized. In particular, communications in our proposal are based only on Wi-Fi in order to reduce the cost to zero, because existing smartphones offer that type of connectivity, and their use has no cost. Although other communication techniques such as 3G, WiMAX and 4G can provide higher transmission speed, longer transmission distance and larger network throughput, one of their main problems is that they are not available everywhere. Besides, existing solutions based on those techniques imply that users may have to change their phones, pay for use, and/or lose their privacy. Furthermore, our proposal is based on 802.11b because it is thought for its use with

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http://dx.doi.org/10.1016/j.sysarc.2013.08.015

reduced speeds in urban environments where traffic congestions and lack of empty parking spaces are problems that need urgent solutions.

The main goal of VAiPho is to increase safety and comfort of driving through the exchange of warning messages about traffic congestions. It also allows taking advantage of additional services such as empty parking space detection, parking reminder and geo-located advertising. One of its main features is that it is a secure system because it protects user privacy and data integrity.

This paper is organized as follows. Section 2 covers some related research on security and applications of VANETs. The technology required by the system specifications is presented in Section 3. Section 4 contains a detailed description of VAiPho structure, including explanations of its main applications. Section 5 describes the VAiPho items that are required for the management of network trust. Security issues related to information content and user anonymity are analyzed in Section 6, while some implementation results are provided in Section 7. Finally, conclusions and future work are presented in Section 8.

2. Related research

A recent survey on research in vehicular ad-hoc networks is provided in [30], where the authors present a review of wireless access standards, trials and simulators of VANETs.

When designing a tool to create a self-organized vehicular network with the goal of increasing road safety, the first prerequisite to be considered is the accuracy and reliability of transmitted information. Thus, security is the most important topic to be taken into account when a communication system is designed for VANETs [20]. In the bibliography we can find several proposed schemes for self-organization in VANETs [29], MANETs [4], and sensor networks [21], which try to solve all or part of the security problems in those types of networks. However, a different approach is presented in this paper, where a self-organized, and at the same time, practical and secure way to deploy VANETs is proposed.

An especially important security aspect of the system is user privacy. Our proposal uses a random pseudonym generator to guarantee with high probability that it is not possible to track a vehicle, and that coincidences between two generated pseudonyms are very unlikely. The paper [1] proposes a specific pseudonym-based scheme to solve the privacy problem caused when GPS coordinates and speeds of vehicles are sent in the beacons. In our proposal, none of those data are sent in beacons. On the other hand, to cope with the issue of changing pseudonyms in improper times or locations, either the mix model [9] or social spots [15] might be combined with our proposal.

With respect to the general objective of discovering and disseminating traffic congestion information, the work [8] has the same goal of this work, but it does not address the important aspect of security of connections. Also many existing centralized GPS software applications offer traffic services based on information provided by local road authorities, police departments and systems that track traffic flow. However, neither of them are real-time data as they do not reflect the events that have just produced, nor respect users' privacy. For instance, Google Traffic [10], TomTom [25], Sygic [23] and Waze [27] are well-known solutions to detect traffic jams. The main difference with our proposal is that all of them need mobile data connection. Another disadvantage is that users completely lose their privacy because they have to provide information about their locations to the companies and other bodies that support the service.

Regarding the search for empty parking spaces a few solutions exist but, to the best of our knowledge, none of them is based simply on a mobile application. The paper [16] presents a proposal where through a device installed in the passenger door, the empty parking space is found and reported to a centralized server through 3G or GPRS. In [18] the authors propose a solution where users can find empty parking spaces managed by RSUs. The paper [3] proposes a dissemination algorithm for spatio-temporal traffic information such as parking space availability, but its goal is not on how the information is obtained, but on how it is transmitted through the network.

The solution to find the parked car is the easiest to implement and consequently several mobile applications can be found for different mobile platforms [5–7,13,14,24,28]. Anyway, such a use of the application is simply a value-added feature for the proposal, and not its main goal.

This paper takes into account that the introduction of a complete model of WAVE-based VANETs is extremely expensive both for users, who would have to buy and install new devices for their vehicles, and for the state, which would have to deploy a huge infrastructure to support VANET services. Therefore, this work proposes a self-organized VANET without any infrastructure, which serves as introduction to a more complex VANET, all this with good levels of reliability and security. Our main goal is to define a simple and scalable model for VANETs where users can cooperate through their mobile devices and obtain updated information of interest about their traffic area in order to choose the best route to their destinations. Our proposal takes into account that the integration of VANETs will be gradual, so that at the beginning there will not be any RSU, and the VANET will start with only a few vehicles. This growth will be faster or slower depending on the popularity, acceptance and ease of use of VANETs. Thus, this paper focuses on the first phase of the deployment. As soon as WAVE-based VANET infrastructures are fully deployed, the proposed solution should be checked to avoid any unnecessary communication.

3. Design requirements

Mobile application development has gone multiplatform, so the system here proposed, called VAiPho, has been tested for Android, Windows Mobile and Symbian, and is being developed for iOS and Windows Phone.

The minimum system specifications (see Fig. 1) for the optimal use of VAiPho are the following:

- *Bluetooth:* to connect the device with the vehicle, providing automatic activation of VAiPho without requiring the user's attention.
- *Wi-Fi IEEE 802.11 b/g:* to allow free exchange of information about possible events between wireless devices.
- *GPS antenna:* to get the GPS coordinates where the events happen and the speed and direction of the vehicle.
- *Storage space:* to provide enough capacity for storing programs and data.
- *Database:* to manage the storage of user data and information about different events such as possible empty parking spaces or reminders of parked vehicles.

VAiPho takes advantage of the powerful application platform capabilities of today's mobile devices. It has no cost at all neither for users nor for governments because it does not require any RSU, and the OBU's role is played by the smartphone inside the vehicle. Furthermore, since people are used to smartphones, the interface is not strange for them, what avoids usual difficulties of learning to deal with new devices.

VAiPho communications are performed using the wireless IEEE 802.11b/g standard. It is well-known that in general this standard is not the best suited for road safety applications because