Computer Networks 112 (2017) 144–166

Contents lists available at ScienceDirect

Computer Networks

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

Review article

Vehicle-to-infrastructure communication over multi-tier heterogeneous networks: A survey

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ARTICLE INFO

Article history:
Received 22 April 2016
Revised 8 November 2016
Accepted 10 November 2016
Available online 10 November 2016

Keywords:
V2I
WAVE
Heterogeneous wireless network
V2I applications
V2I challenges

ABSTRACT

Vehicle-to-infrastructure (V2I) communication is vital in the successful deployment and operation of intelligent transport systems (ITS). One can observe a growing research interest on the effectiveness of V2I communication in the Fifth Generation (5G) networks supporting a co-existence of multi-tier heterogeneous wireless networks with diverse radio access technologies (RATs). The goal of this survey paper is to present the basic characteristics of V2I communication in heterogeneous multi-tier network environments. We first provide an overview of notable V2I applications and few of V2I related projects. We then focus on V2I communications over heterogeneous multi-tier networks. We identify several V2I research challenges and discuss possible solutions.

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1. Introduction

Vehicular networks, a major component of the intelligent transport systems (ITS), aim to contribute towards safer and efficient road traffic. The primary objectives of such networks are to provide road safety and to save invaluable lives. The statistics given in [1] show that about 25,700 people lost their lives and 200,000 were injured due to traffic accidents across the European countries in 2014.Vehicular networks are expected to reduce car crashes by providing various road safety applications such as assisted driver systems and lane changing warnings. In addition, avoiding traffic congestion, provision of effective traffic management and infotainment applications are other key areas of concern for vehicular networks. In vehicular networks, generally, two different modes of communication exist: vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I). Fig. 1 shows a typical example of V2V and V2I communications. In V2V communications, vehicles endowed with Wireless Access in Vehicular Environments (WAVE) [2] interfaces communicate with each other in the form of an ad-hoc network (no centralized control). The main weakness of this form of communication is intermittent vehicular connectivity, especially when the density of vehicles becomes low.

On the other hand, in V2I communication, vehicles exchange data or connect to the Internet through fixed roadside infrastructure components, called Road Side Units (RSU), which are effectively base stations (BS) installed at road intersections on traffic lights or other locations (e.g., bus stops and petrol stations). The RSUs, connected to the backbone IP networks, communicate with the vehicle on-board units (OBU) to receive and transmit different on-road information (e.g., on-road traffic calculation, accident warning etc.) from and to nearby vehicles as they pass by [3]. V2I communication is suitable for real-time applications due to its characteristics as a reliable communication technology. In addition, it is capable of establishing multi-hop communication routes to exchange/forward data with/to other vehicles [4]. V2I communication is useful for on-road vehicular applications such as safety and security, efficient utilization of roads and intersections, infotainment applications, and payments. Besides, the term vehicle-to-road side (V2R) has also been used in referring to the communications between vehicles and ITS infrastructure or WAVE-enabled RSU [5]. However, in this paper, V2R and V2I are used interchangeably.

Research on vehicular communications and networks is gaining popularity worldwide. Multiple government organizations and vehicle makers are investing millions of dollars in it. Some of the notable research projects on V2I communication include ITS projects run by the US Department of Transportation (USDOT), the European Union and Japan. The common objective of these projects is to improve on-road safety by providing drivers with information regarding the surrounding traffic environment. However, as we are slowly approaching the 5G era, providing ubiquitous connectivity

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http://dx.doi.org/10.1016/j.comnet.2016.11.008
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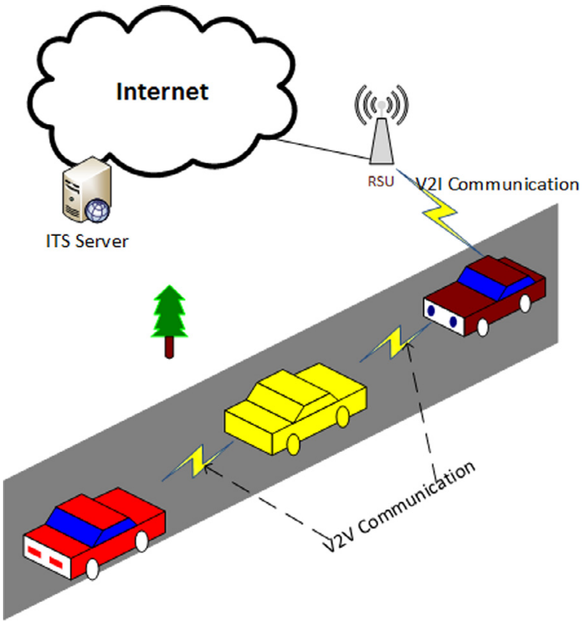

Fig. 1. A typical V2V and V2I communications.

in vehicles will be a challenging issue. 5G is expected to seamlessly integrate heterogeneous multi-tier networks with different underlying network technologies with the aim of providing ubiquitous internet connectivity. Apart from the ubiquitous connectivity requirements, a plethora of other issues with V2I communications will emerge with the deployment of 5G.

Although quite a few of the recent studies have confirmed the viability of heterogeneous wireless access networks (HWNs) to support V2I communications, the presence of multiple underlying networks with different coverage areas, characteristics and QoS requirements pose a plethora of challenges when vehicles move at high-speed. For example, managing the frequent occurrences of vertical (inter-technology) handovers due to high speed vehicles crossing multiple diverse networks, is a considerable issue in terms of providing unhampered QoS and handover performance.

In the recent past, a few publications have surveyed vehicular networks [6–11]. Studies in [6–8] focused on the design architecture of vehicular networks operating over heterogeneous wireless networks, while the security challenges issues were studied in [9]. Also, Vehicular networks enable drivers and passengers in vehicles to socialize by sharing contextual information. The recent study in [10] surveyed the social aspects and features of vehicular networks. Authors described and distinguished the so called vehicular social network (VSN) from the normal on-line social networks (OSN), and a number of research challenges were discussed, including data dissemination, data treatment, and security, to mention a few. Given the particular characteristics of vehicular propagation and channel modelling, the research in [11] surveyed the channel and propagation models which could be suitable for this highly dynamic network. Unlike the current study, none have focused on V2I communications in multi-tier heterogeneous network environments. Here, we present a comprehensive overview of the state of the art V2I communications including different applications, research initiatives, characteristics and requirements for V2I communications in multi-tier HWN environments. We also explore the different research challenges that need to be addressed to make the V2I communications vision a commercially viable reality in 5G networks.

The main contribution of this paper is to provide an insight into V2I communications over heterogeneous multi-tier networks. This study may be useful for the design and successful deployment of V2I communications over 5G networks. For each research issue discussed, the work also surveys different solutions proposed by the V2I research fraternity. Insights into each of the issues and open research questions are also included.

The rest of the paper is organized as follows. In Section 2, we introduce V2I communications standards; Section 3 presents the various applications of V2I communications and discusses a few of the selected V2I related projects. Section 4 discusses the characteristics and requirements of V2I communications in heterogeneous multi-tier environments with diverse underlying network technologies. Sections 5 and 6 survey the important V2I communications-related research challenges in heterogeneous multi-tier network environments along with the various solutions proposed by the research community. The paper concludes with Section 7.

2. V2I communication standards

Standardization efforts in vehicular networks have resulted in many standard protocols utilized for the advancement of vehicular network technology. Dedicated short range communication (DSRC) and WAVE are typical examples of vehicular network standards protocols. The main objectives of these protocols involve defining the frequency allocation, communication architecture, messaging, application management and security algorithms. On the other hand, the 3GPP Service and System Aspects Group is currently pursuing a study on 'LTE support for V2X services' to be tentatively published soon [12]. The LTE-V2X standard is expected to be released in release 14 at the end of the year 2016 [13]. The main communication standards for vehicular network are outlined here.

2.1. Dedicated short range communication (DSRC)

DSRC has been developed and standardized in the USA [14] and it is derived from the IEEE 802.x family; it uses licensed spectrum at 5.9 GHz with seven channels of 10 MHz bandwidth (5.850–5.925 GHz). This is half of the bandwidth used in IEEE 802.11a. Among the seven channels, two at the ends are reserved for special uses; one in the centre is the control channel (CCH) and it is limited to safety applications, and the rest are service channels (SCH) available for both safety and non-safety usage. It is worth noting that the regional (USA, Japan and Europe) standardization of DSRC was slightly different in terms of selected radio frequencies, allocated bandwidth, and the number of channels, data transmission rate, and coverage. The details of the DSRC specification can be found in [15].

2.2. WAVE

As previously mentioned, DSRC is derived from IEEE802.11a. The major modification was made at the physical layer, where the authentication process was suppressed to speed up the network discovery and selection processes. However, DSRC suffers from multiple overheads inherited from the MAC layer and this fact makes it difficult to provide the fast data exchange compulsory for vehicular networks [14]. To address this issue, the American Society for Testing and Materials (ASTM) working group, ASTM 2313, migrated the DSRC effort to IEEE802.11 p WAVE, which integrates both the MAC and physical layers [14]. WAVE defines two classes of devices: OBU and RSU. The former is essentially used as a stationary device, while the latter is used as mobile device. WAVE uses Orthogonal Frequency Division Multiplexing (OFDM) to divide the signal into a number of narrowband channels. In the WAVE stack, the access media and physical layers are derived from IEEE802.11a, while the operational functions and channel planning are handled by IEEE

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