Computer Communications 39 (2014) 11–21

Contents lists available at ScienceDirect

Computer Communications

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

A multi-priority supported medium access control in Vehicular Ad Hoc Networks

Caixing Shao [a], Supeng Leng [a,*], Yan Zhang [b], Huirong Fu [c]

[a] Key Lab of Optical Fiber Sensing and Communications, School of Communication & Information Engineering, University of Electronic Science and Technology of China, Chengdu 611731, China
[b] Simula Research Laboratory, Lysaker 1325, Norway
[c] Department of Computer Science and Engineering, Oakland University, Rochester, MI 48309, USA

ARTICLE INFO

Article history:
Available online 15 November 2013

Keywords:
Vehicular Ad Hoc Network
Medium access control
Multi-priority
p-Persistent
Markov model

ABSTRACT

In recent years, Vehicular Ad Hoc Networks (VANETs) experience growing interest in both academia and industry. VANETs apply multiple channels, namely Control Channel (CCH) and Service Channels (SCHs), to provide road safety services and improve the comfort and efficiency of driving. Based on the time slotted *p*-persistent channel access mechanism, this paper proposes a multiple priority supported medium access control (MAC) protocol for VANETs, which differentiates the packets into multi-priority on the CCH. A Markov analytical model is presented to optimize the packet transmission probabilities with different priorities and the adjustable intervals of the CCH and SCH. Moreover, a contention-free ACK scheme is reported to guarantee the reliable broadcast of the safety packets and avoid collision caused by numerous ACK packets on CCH. Simulation results indicate that the proposed MAC protocol is able to ensure the prioritized transmission of the safety packets, and it can achieve optimal system performance in terms of saturated throughput.

1. Introduction

A large number of interesting and desired applications of Intelligent Transportation Systems (ITS) are stimulating the development of Vehicular Ad Hoc Networks (VANETs). A VANET normally consists of a number of vehicles that are equipped with wireless communication devices, GPS and digital maps [1]. Through Inter-Vehicle Communication and Vehicle-to-Roadside Communication, vehicles can exchange information for the enhancement of driving safety and the comfort of drivers and passengers. Applications in VANETs span from road safety alarm, driver-assistance messages or hazardous road condition reports [2], to various convenience and commercial applications, such as local advertisements, traffic reports or parking information disseminated in a manner of delay tolerant networks (DTNs) [3,4]. The US Federal Communications Commission (FCC) has allocated 75 MHz in the 5.9 GHz band to be used exclusively for vehicular communications. The IEEE Wireless Access in Vehicular Environments (WAVE) architecture includes the standards IEEE 802.11p [5] and IEEE 1609.4 [6]. IEEE 802.11p working group investigates a new PHY/MAC amendment of the 802.11 standard for VANETs. The Orthogonal Frequency Division Multiplexing (OFDM) technique is employed in IEEE 802.11p, leading to 27 Mb/s data rate over each channel with 10 MHz bandwidth.

The IEEE 1609 working group standardizes the Dedicated Short Range Communication (DSRC) protocol stack between the link layer and the application layer of VANETs. Fig. 1 illustrates that the overall 75 MHz bandwidth in the 5.9 GHz is divided into seven frequency channels. The channel CH178 is the public Control Channel (CCH) for the delivery of the safety information and the exchange of control packets among vehicles, for example, emergency packets transmitted by a crash car to warn other vehicles in the vicinity. The other six channels are Service Channels (SCHs) that support the transmission of non-safety applications, such as entertainments, news, advertisements and Internet access. In order to coordinate the channel access to the CCH and multiple SCHs, IEEE 1609.4 has developed a globally synchronized coordination scheme based on the Coordinated Universal Time (UTC) [6]. The channel access time is divided into fixed intervals with 100 m s of each. All devices need to tune to CCH during CCH intervals for the delivery of safety packets and control packets. During SCH intervals, each device switches to a specific SCH to perform non-safety applications.

However, with a contention based medium access mechanism, the current WAVE MAC framework defined by IEEE 802.11p and IEEE 1609.4 is not efficient to support either delay sensitive

* Corresponding author. Address: School of Communication & Information Engineering, University of Electronic Science and Technology of China, Chengdu 611731, China. Tel./fax: +86 28 61830520.

E-mail address: spleng@uestc.edu.cn (S. Leng).

0140-3664/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.comcom.2013.11.002

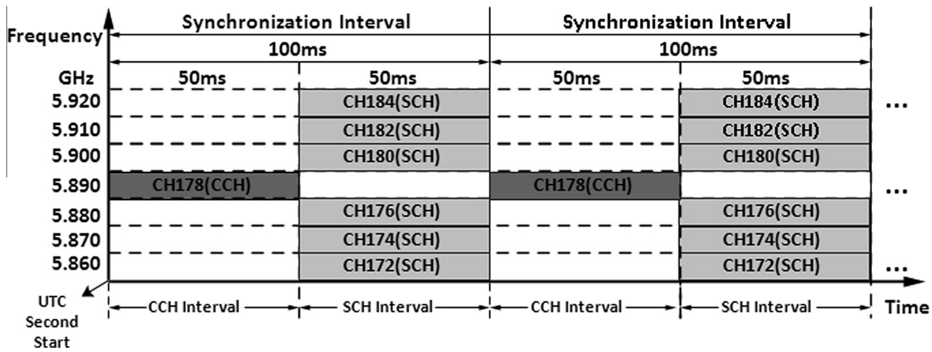

Fig. 1. Frequency channels of the 5.9 GHz WAVE system.

applications or throughput sensitive applications, especially in a dense host environment [7]. If hundreds of cars intend to access CCH in a crowded crossroad, the transmission of control packets, safety packets and WAVE Service Advertisement (WSA) packets will cause severe channel congestion. The effective throughput of CCH will be significantly reduced due to the continuous packet collision and backoff on the channel. In addition, considering the fixed value of the CCH interval and SCH interval, the limited length of CCH is unable to provide sufficient delivery capability for large number of safety packets and control packets. Furthermore, the nodes cannot make enough reservation for data transmission during SCH intervals. In this case, vehicular safety information cannot be transmitted promptly without an efficient multi-priority differentiated MAC protocol.

In this paper, we proposed a multi-priority supported *p*-persistent (MP) MAC protocol for VANETs. The proposed MAC protocol has the following distinguishing features which make it different from the existing schemes. Firstly, the MP MAC protocol sorts the service packets delivered on the CCH into two priority categories. Packets generated by event-triggered safety applications are classified as the safety packets with the higher priority AC_1, and the remaining packets, i.e., periodic packets and WSA packets, transmitted on CCH are classified as the lower priority AC_2. A packet differentiation mechanism can ensure the prioritized transmission of the safety packets. Secondly, a multi-priority Markov chain model is presented to optimize the interval ratio between the CCH and the SCH according to the dynamic traffic conditions. Thirdly, with the time slotted based *p*-persistent MAC scheme, the WAVE nodes attempt to transmit different priority packets at the beginning of a time slot with the dynamically optimal transmission probabilities, which can effectively avoid transmission collisions, so that the optimal system performance in terms of saturation throughput can be achieved. Finally, a contention-free ACK scheme is devised to confirm the reliable transmission of the safety packets and reduce channel collision on the CCH.

The rest of this paper is organized as follows. Section 2 presents a brief survey on the current investigation on MAC schemes for VANETs. Section 3 describes the proposed MP MAC protocol in detail, and Section 4 presents the theoretical analysis in terms of the transmission probabilities and the optimal ratio between the CCH interval and SCH interval. Performance evaluation through both theoretical analysis and simulations is presented in Section 5. Lastly, Section 6 concludes the paper.

2. Related works

In a VANET scenario with dense vehicles, lots of vehicles attempt to send safety packets and exchange control packets on CCH, which leads to serious channel contention and long latency for the dissemination of safety packets [8]. It is necessary to classify the packets on CCH with different priorities to ensure the real-time transmission of safety packets. The study in [9] sorted the packets delivered in VANETs to different priorities based on the relevance of the vehicle information and illustrated that packets of nodes applying the IEEE 802.11e-based architecture contained in a high-priority queue were more likely to win the channel contention compared to those waiting in a low-priority queue. Moreover, the authors proposed that this relevance-based priority scheme can help realize the scalability of VANETs by optimizing the application benefit and the bandwidth usage. However, this scheme cannot guarantee preemptive transmission of the safety critical packets, especially in densely populated network scenarios. The study in [10] presented that the packet traffic generated by event-driven safety applications has higher priority compared to the remaining network traffic. Using birth-death process analysis, the authors found that the average number of the nodes for receiving packets with high-priority increases as a function of the transmission range. However, the work assumed that at most only one event-driven safety packet can be propagated in the network at any time, whereas vehicle nodes may transmit multiple safety packets simultaneously in a practical VANET environment. Literature [11] proposed a 2-D embedded Markov chain model to analyze the impact of differentiated channel access parameters such as Arbitration Interframe Space (AIFS) and contention window (CW). Different with the above schemes, our work considers how to dynamically adjust the transmission probabilities of different priority packets for the purpose of maximizing saturated system throughput in variable channel conditions.

In a dense VANET environment, severe congestion may occur on the CCH with a contention based MAC scheme. To avoid collisions on the CCH, many research works have been done based on Time Division Multiple Access (TDMA) MAC schemes in VANETs. The study in [12] presented a multichannel TDMA-based MAC (VeMAC) protocol, to improve the throughput on CCH. The transmission collisions on CCH can be reduced since the disjoint sets of available time slots are assigned to vehicle nodes moving in opposite directions and to RSUs (Road Side Units). However, the mechanism treats the vehicle nodes and RSUs as the same, and it ignores the functionality of the RSUs as the center nodes. Another TDMA-based MAC protocol was proposed in [13], where the network is partitioned into a number of virtual segments. Medium access control within each segment is accomplished by a local coordinator vehicle node using a time-slot-scheduling mechanism. Nevertheless, with the high mobility and hidden terminals in VANETs, this scheme cannot significantly improve the network performance since a vehicle node rather than the RSU is selected as the local coordinator. Furthermore, these existing TDMA-based MAC protocols fix the CCH interval to 50 m s. Different from the above two