Enhancement of MAC Technology for Improved Vehicular Networking

#Jong-Moon Chung [1], Minseok Kim [1], Daeyoung Lee [1], Sangwoo Lee [2], Hyun Seo Oh [2]
[1] School of Electrical and Electronic Engineering, Yonsei University
Seoul, Republic of Korea, {jmc, msk84, leedy}@yonsei.ac.kr
[2] Telematics & Vehicle-IT Convergence Research Department, Electronics and Telecommunications Research Institute (ETRI), Daejon, Republic of Korea

Abstract

A variety of wireless technologies will soon become available for vehicles and road equipments, enabling new intelligent transportation system (ITS) applications. In this paper, an introduction on medium access control (MAC) technologies for vehicular networking is presented. In addition, the limitations and corresponding enhanced techniques are introduced as well.

Keywords: Intelligent transportation system, vehicular communications, medium access control

1. Introduction

In recent years, ITSs have become an attractive field of research. Applications of ITS technologies include public safety support, intelligent traffic management, as well as multimedia contents delivery. Some examples are cooperative collision warning, road condition notification, traffic congestion management, map/content downloading, and electronic toll payment, and many more. In the perspective of vehicular communications and networking, ITS applications require high reliability while demanding short access delay, due to the highly dynamic and spontaneous nature of vehicular communications. Satisfying these requirements has been a main challenge in providing wireless access to vehicles.

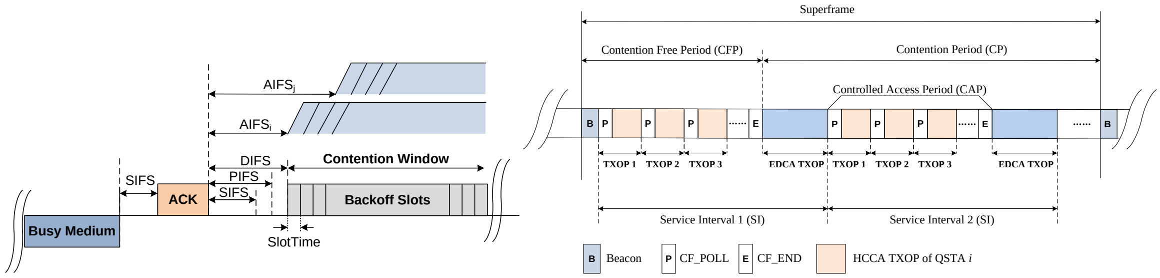
In July 2010, the IEEE 802.11p standard for wireless access in vehicular environment (WAVE) was published. The IEEE 802.11p includes some features on the MAC and PHY layer to provide wireless access to the vehicles that operate in the 5.9 GHz dedicated short range communication (DSRC) band [1]. The purpose of WAVE is to provide vehicles seamless and interoperable connectivity using widely deployed WLAN technologies. The MAC layer of IEEE 802.11p introduces several amendments and additions to the legacy IEEE 802.11 MAC. For instance, authentication and association procedures in communication group setup are removed to support the dynamic vehicular nature and stations are enabled to communicate outside the context of any basic service set (BSS) as in ad hoc networks. In addition, the channel access mechanism of IEEE 802.11p relies on the enhanced distributed channel access (EDCA) and hybrid coordination function controlled channel access (HCCA) of the IEEE 802.11e, where the default scheme is EDCA, and HCCA is considered as an option [2]. More details will be explained in the following section.

This article provides an overview of MAC technologies for improved vehicular communications. The remaining parts of this article are organized as follows. In section 2, the details of MAC technologies of the IEEE 802.11p and their limitations are introduced. Some other techniques to enhance the MAC layer performance of vehicular network are presented in section 3. Finally, section 4 concludes the article.

2. Medium Access Control in IEEE 802.11p

2.1 EDCA and HCCA

EDCA is a random access scheme based on carrier-sense multiple access with collision avoidance (CSMA/CA). After a station senses the medium being idle for an arbitration inter-frame space (AIFS) duration, it draws a random number out of its current contention window size and then accesses the channel when its backoff counter expires from the countdown of the selected random number. Additionally, EDCA introduces four access categories (ACs) to support quality of service (QoS) requirements of different types of traffic. In contrast to the EDCA, HCCA is based on a polling mechanism controlled by the hybrid coordination function (HCF). In ITS applications, the HCF would gather traffic requirements of the vehicles, and then schedule the duration and period of each vehicle's channel access. By individually polling each vehicle, the HCF allocates appropriate transmission opportunities (TXOPs) to each vehicle providing contention-free channel access. Figure 1 (a) and (b) represents typical examples of medium access of EDCA and HCCA, respectively.



(a) (b)

Figure 1: Medium Access Mechanism in (a) EDCA and (b) HCCA.

2.2 Limitations of IEEE 802.11p MAC

Owing to its inherent characteristic of being a random backoff based scheme, EDCA imposes some limitations when considering vehicle-to-infrastructure (V2I) communications. More specifically, EDCA could result in unpredictable delays. Commonly, ITS applications require relatively short time delays (especially for time-critical safety applications). Unnecessary backoff procedures would result in a waste of time and bandwidth. Furthermore, fairness between the users cannot be guaranteed when EDCA is applied, and only the minimum level of QoS can be provided. On the other hand, in regards to HCCA, the reference scheduler in the IEEE 802.11e standard only considers fixed size TXOPs. As a result, HCCA is unable to dynamically assign resources to traffic with dynamic and urgent demands, and therefore would not be able to adapt to the rapidly time-varying channel conditions of highly mobile vehicular environments. In addition, polling each individual vehicle at a time is clearly not efficient. More details of the EDCA and HCCA mechanism as well as their potential limitations can be found in [3]-[5].

3. Enhanced MAC for Vehicular Networks

This section introduces enhanced MAC technologies for improved vehicular networking based on enhanced vehicle-to-vehicle (V2V) and V2I communications.

3.1 Vehicle-to-Vehicle Communications

For time-critical safety related applications, efficient V2V communications are of great importance. In safety critical applications, it is important to rapidly and reliably forward warning messages in a multi-hop manner between vehicles. This is especially important because the IEEE 802.11p PHY has a limited transmission range which may not be sufficient in reaching a wide enough area transmitted from a single station. However, using multi-hop broadcasting communications may lead to *broadcast storm* problems due to an excessive number of redundant broadcast messages. In [6], the authors propose a simple probability based methods called weighted *p*-persistence and slotted *p*-persistence, which are shown in Figure 2 (a) and (b), respectively.

Weighted *p*-persistence assigns higher transmission probability to vehicles that are located farther away from the initially broadcasting vehicle. The slotted *p*-persistence scheme divides the broadcasting region into multiple time-slots, where a vehicle waits for its allocated time-slot and forwards a packet with probability *p*. If a duplicated packet arrives while waiting for its time-slot, a vehicle discards the packet and does not forward it. The abovementioned methods are simple and easy to implement, and thus, can be considered as a fundamental schemes when considering efficient broadcast storm mitigation techniques.

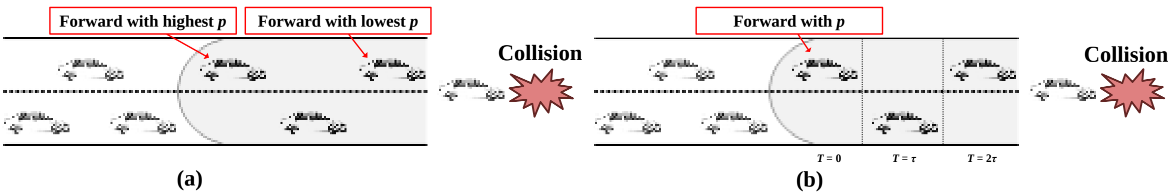


Figure 2: Broadcasting Techniques (a) Weighted *p*-persistence and (b) Slotted *p*-persistence.

Recently, the authors of [7] define two metrics to measure the performance of broadcasting, which are *efficiency* and *reliability*, and proposed strategies to maximize the broadcast efficiency. The authors of [8] propose a Region-based Clustering Mechanism (RCM) to reduce the contention period, such that timely and reliable data delivery for mobile vehicles can be achieved.

3.2 **Vehicle-to-Infrastructure Communications**

For V2I communications, a time coordinated multiple access scheme, named WAVE point coordination function (WPCF) is proposed in [5]. WPCF focuses on guaranteeing medium access while reducing the polling overheads. WPCF also provides a way to improve channel utilization in order to reduce the waste due to an excessive allocation of TXOPs. These two were the main performance degrading factors of the former contention-free access schemes like HCCA.

In WPCF the order of channel access is coordinated by the road-side unit (RSU), and each of the on-board units (OBUs) who receive the ordered list of access from the RSU configures its waiting time (i.e., WPIFSs) based on

$$WPIFS[N] = SIFS + (N \cdot T_{slot}) \quad (1)$$

where T_{slot} is the slot time. Therefore, the OBU that appears first on the list will have the smallest $WPIFS[N]$, and consequently will obtain highest priority in channel access. The allocated $WPIFS[N]$ values of lower priority OBUs will be larger, which will result in larger wasted time between transmissions. In order to overcome this issue, the WPIFS of all OBUs are simultaneously reduced by equal amounts (T_{slot}) each time the RSU issues an ACK based on the reception of the final fragment packet of the OBU currently transmitting. For the case where an OBU may not have anything to transmit, although it is the next OBU in the sequence to transmit, the OBU will just remain silent, enabling the OBU with the next highest access priority (i.e., the OBU with the next smallest WPIFS value) to transmit. As the RSU sends an ACK corresponding to the final packet of each OBU, then all OBUs will reduce their WPIFS value by two T_{slot} amounts, because one OBU skipped its transmission turn. Since the ACK frame of the current IEEE 802.11p specifications already includes the OBU MAC address/ID and a flag indicating that this is an ACK corresponding to the last fragment of packet transmissions, this process can be executed without any additional modifications to the current ACK message in IEEE 802.11p. The proposed channel access scheme during service channel (SCH) interval is shown in Figure 3. As a result of assigning an ordered sequence at the beginning, individual control of the polling procedure is neglected and there is no need to assign a TXOP period. By eliminating a complicated control sequence to set up the polling procedure, the complexity and overhead can be significantly reduced. In addition, if a polled OBU does not send any frame, the next OBU will be able to immediately access the channel after an extra slot time. For the WPCF, the *WPIFS*[*N*] assigned is systematically reduced through reception of ACK frames, resulting in a more flexibly utilized channel model.

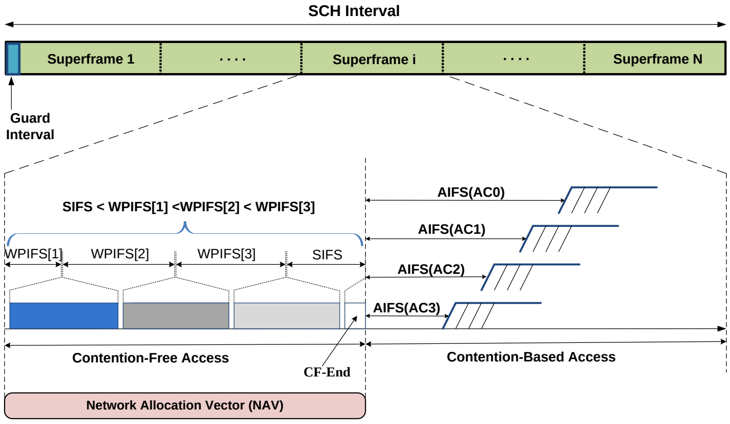


Figure 3: WPCF Contention-Free Access within the SCH Interval.

4. Conclusion

In this article, we provided an overview on various MAC techniques for vehicular networking. The contents provided include the mandatory IEEE 802.11p MAC scheme and its related/modified techniques. The various techniques mentioned above can be applied in an appropriate situation, or they can be applied in a hybrid way.

References

[1] "IEEE 802.11p, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 6: Wireless Access in Vehicular Environments," IEEE Std. 802.11p-2010, 2010.
[2] J. Zhu, S. Roy, "MAC for Dedicated Short Range Communication in Intelligent Transport System," *IEEE Commun. Mag*., vol. 41, no. 12, pp. 60-67, 2003.
[3] S. Mangold, S. Choi, G. R. Hiertz, O. Klein, B. Walke, "Analysis of IEEE 802.11E for QoS Supprot in Wireless LANs," *IEEE Wireless Commun. Mag*., vol. 10, no. 6, pp. 40-50. 2003.
[4] A. Grillo, M. Macedo, M. Nunes, "A Scheduling Algorithm for QoS Support in IEEE 802.11e Networks," *IEEE Wireless Commun. Mag*., vol. 10, no. 3, pp. 36-43, 2003.
[5] J.-M. Chung, M. Kim, Y. S. Park, M. Choi, S. Lee, H. S. Oh, "Time Coordinated V2I Communications and Handover for WAVE Networks," *IEEE J. Sel. Areas Commun*., vol. 29, no. 3, pp. 545-558, 2011.
[6] N. Wisitpongphan, O. K. Tonguz, J. S. Parikh, P. Mudalige, F. Bai, V. Sadekar, "Broadcast Strom Mitigation Techniques in Vehicular Ad Hoc Networks," *IEEE Wireless Commun. Mag*., vol. 14, no. 6, pp. 84-94, 2007.
[7] F. Ye, R. Yim, S. Roy, J. Zhang, "Efficiency and Reliability of One-Hop Broadcasting in Vehicular Ad Hoc Networks," *IEEE J. Sel. Areas Commun*., vol. 29, no. 1, pp. 151-160. 2011.
[8] Y. Lai, P. Lin, W. Liao, C. Chen, "A Region-Based Clustering Mechanism for Channel Access in Vehicular Ad Hoc Networks," *IEEE J. Sel. Areas Commun*., vol. 29, no. 1, pp. 83-93, 2011.

Acknowledgments

This research was supported by the Information Technology Research Center (ITRC) program (NIPA-2011-C1090-1111-0006) supervised by the National IT Industry Promotion Agency (NIPA) of the Ministry of Knowledge Economy (MKE) and the National Research Foundation (20100028224) of the Ministry of Education, Science & Technology (MEST) of the Republic of Korea.