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Improvement of polling and scheduling scheme for real-time transmission with HCCA of IEEE 802.11p protocol

ZHANG Bing[1], MA Mao-de[2] (✉), LIU Chun-feng[1], SHU Yan-tai[1]

1. School of Computer Science and Technology, Tianjin University, Tianjin 300072, China
2. School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore

Abstract

This paper addresses the issue of real-time data transmission in vehicles to roadside (V2R) environment by the hybrid coordination function (HCF) of controlled channel access (HCCA) specified by the IEEE 802.11p standard. HCCA is one of the medium access mechanisms in the IEEE 802.11 standard, and uses the polling scheme similar to the point coordination function (PCF) to provide reliable quality of service (QoS), which may cause resource overshooting and high time consuming. This paper tries to improve the performance of the HCCA polling scheme and designs new data transmission scheduling scheme. The simulation results of the proposal are compared with those of the standard strategy. Simulation results demonstrate that the improved HCCA has lower delay, loss rate, and higher throughput than those of the standard one.

Keywords IEEE 802.11p, HCCA, V2R, polling, scheduling

1 Introduction

In recent years, along with the continuous development of intelligent transportation systems (ITS), vehicular networks have attracted more and more attentions. To construct an ITS, which could supports the applications including public safety, traffic condition, travelling support and entertainment information, etc. a stable and continuous wireless network, which can broadcast some information in the traffic such as urgent information, traffic related information, un-urgent and entertainment information, is highly demanded. However, in the current vehicular networks, the features of high mobility, frequent disruption and time-varying channel condition make a challenge on the network continuous connection. Especially, in a sparse highway situation, real time information forwarding and receiving becomes an obstacle for most of the Ad-hoc vehicles to vehicles (V2V) communications. Besides, instant accidents in a high way may cause hours or even days of traffic congestions. Therefore, it is essential to keep a robust communication network with less interruption for vehicles with the aim to ensure public safety and high efficiency of traffic flow. In a highway environment, the roadside units (RSU) are normally located apart along the highway. The on-board units (OBU) in vehicles could connect to the RSUs when they are in the coverage of each RSU. In addition, the roadside infrastructure is much more mature with the current wireless local area networks (WLAN) technology or other cellular systems. Thus, it is more feasible for the fast moving vehicles to join a stable roadside infrastructure and exchange data quickly and efficiently.

In 2009, the European Telecommunications Standards Institute (ETSI) proposed IEEE 802.11p - an amendment to the IEEE 802.11 standard for wireless access in vehicular environments (WAVE) [1]. The purpose of IEEE 802.11p protocol is to allow an IEEE 802.11-compliatnt device to communicate directly with another such device outside of an independent or infrastructure network [1]. IEEE 802.11p is allocated with 75 MHz of dedicated short range communications (DSRC) in 5.9 GHz spectrum with 7 channels–one control channel (CCH) and six service

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Corresponding author: MA Mao-de, E-mail: emdma@ntu.edu.sg
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channels (SCH). CCH is reserved to exchange management data and very urgent information, while SCH is used to transmit all other un-urgent information. OBUs switch between CCH and SCH channels in CCH and SCH interval, the length of which are tunable. At MAC layer, two medium access mechanisms are applied: enhanced distributed coordination access (EDCA) and HCCA, both of which are proposed based on the IEEE 802.11e standard. The EDCA provides a distributed access method which can support service differentiation among traffic, while the HCCA works based on the central coordination and scheduling to allocate resources. The HCCA mechanism employs a polling scheme same as the one in IEEE 802.11e standard for real-time data transmission service due to its ability of high QoS guarantee, which is also essential for emergency information and some traffic related information delivery in the vehicular environments.

By the WAVE, information that needs reliable real-time delivery, such as position information and emergency information, can also be accessed by the HCCA mechanism. The HCCA mechanism manages the access to the wireless medium using a central HCF coordinator (HC). The HC gains control of the medium by waiting a shorter period between transmissions than that of the EDCA procedure, and other nodes gain access to transmission medium by listening to polling frame from the HC. In the V2R scenarios, the RSUs hold the function of the HC, while OBUs will gain complete control over channel in sequence once it has got the instruction from the HC. As shown in Fig. 1, one HCCA superframe is composed of a contention free period (CFP) and a contention period (CP). Data delivered by the polling scheme are issued in the CFP, while others are issued in the CP. In the CFP duration, an OBU should respond within a SIFS period once it has received a polling frame from the HC. If the OBU has no queued packet to send, it will send a null frame back. This polling scheme has been proved of high-efficiency on data scheduling and QoS reliability. Besides, in the IEEE 802.11p standard, since only management data and high urgent data can be broadcasted during CCH interval, the usability of CCH and SCH could be disequilibrium.

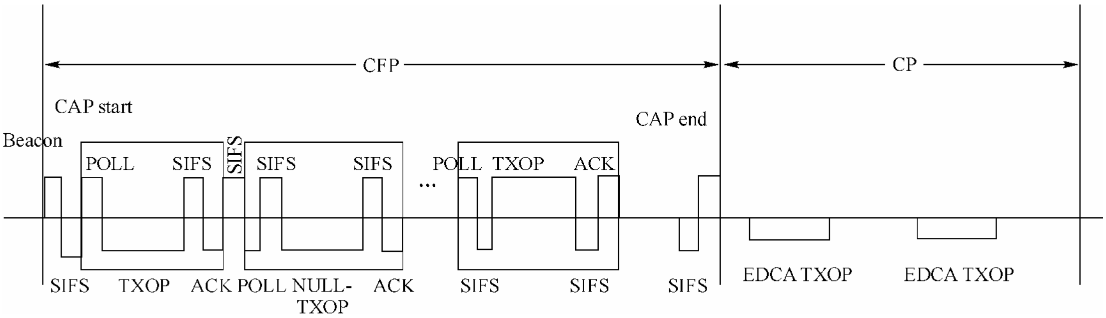


Fig. 1 HCF superframe construction in IEEE 802.11

To adapt to the changing demands from the OBUs and avoid transmission data redundancy, we change the working mode of the HC release resources to OBUs passively. By our proposed solution, in the CFP period, the HC only allocates the resource to OBUs according to the QoS transmission requirements of the OBUs. The OBUs will send transmission requests to the HC by the EDCA scheme in the CP duration once they have high priority data to transmit, while the HC collects these requests in the beacon intervals and reschedules the assignment according to the priority of requests, the length of request duration, and that transmission deadline. Then, the HC packs these requests in the next broadcasting beacon frame. An OBU will gain the controls of resources according to the scheduling result by HC. To enhance the channel utilization, the QoS data transmission in the CFP duration will be delivered in the CCH intervals by the HCCA scheme. Since the transmission requirements are sent by the EDCA scheme, it may increase the transmission delay for the first QoS data frame. However, along with the increasing of transmission of the QoS demanded data, the improved mechanism has significant advance over the scheme specified in the standard.

The remainder of the paper is organized as follows. In Sect. 2, we describe the system model and related work. In Sect. 3, based on the description of the system model, we present the improved HCCA protocol and corresponding scheduling scheme. In Sect. 4, we analyze the performance of the proposed solution by simulation experiments over QualNet platform. In Sect. 5, we conclude the paper with a summary.

2 System model

2.1 Network environment

In this paper, we consider a V2R network in highway environments. The network being considered is a code division multiple access (CDMA) vehicular network with a centralized coordinator. To simplify the environment, we assume that all the OBUs are always under the cover of RSUs without the problems caused by handovers. In the network, n mobile nodes share a CCH and 6 SCHs. These nodes switch between CCH and SCHs in alternative intervals. The CCH is only used for the transmission of management information and urgent message delivery, while the SCHs are used for payload data delivery. In this network, the HCCA scheme is applied as medium access mechanism and transmission interval is considered as a superframe. One superframe is composed of a CFP and a CP. CFPs occur at a repetition interval of three delivery traffic indication messages (DTIM) and shall be synchronized with beacon intervals. The RSU starts and ends a CFP by broadcasting a START_CAP frame and END_CAP frame. Messages are transmitted within the granted transmission opportunity (TXOP) [2], which is a specified time period for the mobile node to start its transmission to the moment the transmission is over. In the controlled access phase (CAP) [2], one TXOP can be used by both CFP and CP. But the TXOP by the EDCA scheme can only be used for CP. To simplify the model, the CAP TXOP is assumed to be used only for CFP. the Since the IEEE 802.11p protocol follows IEEE 802.11e protocol to support QoS, the access categories will be classified as background (BK), best effort (BE), voice (VO) and video (VI). Messages in different categories are set with different transmission priority. However, this classification cannot satisfy the demands of data delivery situation in IEEE 802.11p. In this paper, messages of urgent information and the real-time traffic status in the high way will be considered as the highest priority and delivered with CAP TXOPs.

2.2 Related work

The research on vehicular networks had attracted much attention since IEEE 802.11p has been published. Some of the products of the vehicular communication with ability to provide communication services have already come out. In Ref. [3] Jong et al. propose a time coordinated MAC protocol named WAVE point coordination function (WPCF). It has demonstrated a mathematical derivations and simulation analysis of the WPCF protocol. In addition, it has provided a technical enhancement on the seamless communication services for soft-handover and hard-handover over a V2I communication environment. Considering the different data classification in vehicular environments, the access category defined in IEEE 802.11e could not satisfy the vehicular environments. IEEE 802.11p standard has used the EDCA and HCCA schemes defined in IEEE 802.11e standard for the medium access and provide QoS supports. IEEE 802.11e standard has classified 4 access categories (AC): BK, BE, VO and VI. However, these categories could not cover all the data types in a vehicular network. Therefore, a new classification is required for MAC protocol for vehicular networks. In Ref. [4] Jose et al. classified data into four categories: safety-related urgent information, vehicles' presence information, non-urgent information and non-safety- related messages. Besides, it has proposed an analytical tool to evaluate the performance of WAVE and analysis WAVE performance with Markov chain mathematically. In Refs. [5–8], Nakjung et al. focused on V2R communications in vehicular networks and proposed solutions to tackle the performance descending caused by signal relaying, error bursting and delivery disruption, etc. Many research and analysis have been carried out to improve the performance WLAN since the IEEE 802.11e has been published in 2004. These work mostly focuses on improvement to the EDCA mechanism, analyzing with Markov chain or queuing theory, such as the work in Refs. [9–10]. The work in Refs. [3,11] demonstrates a comprehensive study of EDCA scheme with analysis on the throughput performance of differentiated service to various applications. Another recursive method capable of calculating the mean access delay has also been proposed in Ref. [12]. The HCCA scheme, on the other hand, has rarely mentioned because of its inflexibility using centralized control and assignment infrastructure. In Refs. [13–14], an improved scheduler of HCF has been designed to provide and enhance the network performance by archiving the delay upper bound for various ranges of traffic load.

3 Design of the proposed solution

IEEE 802.11e provides two medium access mechanisms of EDCA and HCCA. The HCCA guarantees a reliable

QoS service with HCF. By the HCF, the basic unit of the allocation of the transmission right is the TXOP. Every OBU would occupy medium either by competition or being granted by HC to access medium within its TXOP. The RSU grants TXOPs to each OBU using polling scheme, which is similar to that of PCF specified in IEEE 802.11a/b/g. By the HCF, an OBU could get control of the medium access either in the CFP duration with QoS-POLL frame, or in the CP duration with QoS-POLL(+) frame. In our design, we simplify the scenario by omitting the second situation. In the duration of the superframe under the HCCA schem, a RSU starts a CAP by broadcasting a START_CAP frame. After that, the RSU starts sending polling frame to each OBU in the recommended poll list to trigger CAPs. When all the CAPs have been finished, the RSU sends an END_CAP frame to finish CFP duration. The HC gains the control of the medium assignment and issues the CF-POLL frame to OBUs during the CFP by waiting shorter period than that by the EDCA scheme. The HCCA cannot dynamically adapt resources according to static recommended OBUs poll list, which is constructed periodically. Thus the fixed TXOP allocation sequence may result in a potential waste of the time and the resources for the transmission. In our design, we try our best to decrease the polling overhead and improve the channel utilization.

3.1 Dynamic polling mechanism

According to the current standard, the RSU gathers the names of the OBUs that require QoS service into its own recommendation poll station list. In the CFP duration, a RSU sends polling frames in sequence to all the OBUs in the poll list to grant medium access opportunities after a short interframe spaces (SIFS). Once the OBUs find their MAC addresses appeared in the polling frame, they will take over the medium after a SIF interval and start their TXOP periods. After the last OBU has finished its transmission and handed over the medium control back to the HC, the HC broadcasts a CAP_END message to all OBUS, and the CP duration starts. If an OBU has no packet with QoS demand in its transmission queue, it will either send a null-frame or send nothing back to the RSU, which may cause polling frame transmission overshooting and resource dissipation. In our improved design, the priority of packets will be classified by the MAC layer at the OBUs. If some packets need QoS transmission by the HCCA scheme, it will generate a transmission requirement including the desired TXOP length and the priority by the HCCA transmission as the highest priority. The requirements will be sent to RSUs by the EDCA scheme as soon as possible. When the HC gathers all the HCCA requirements from the OBUs in each beacon interval, it will broadcast the list in each beacon frame. After the OBUs get their TXOP durations and transmission order from broadcasted beacon frame, they may configure their point interframe space (PIFS) based on the transmission order and the granted length of TXOPs. One OBU could send more than one requirements via an EDCA TXOP. And their requirements will be processed together in the next beacon frame. This may increase the transmission delay for the first transmission. However, the delay will taper off with the increment of HCCA requirements. The PIFS for the *N*th OBU can calculated as below:

$$P[N]=\tau_{\text{beacon}}+n\tau_{\text{SIFS}}+(n+1)\tau_{\text{TXOP}} \tag{1}$$

where τ_{beacon} means beacon transmission time, every OBU will occupy medium for TXOP after waiting SIFS, τ_{SIFS} stands for the SIFS interval, τ_{TXOP} stands for the TXOP interval. Specified in the standard, both of the HCCA and the EDCA schemes are operating in the SCH interval. The CCH interval is only used for management information and some urgent information broadcasting. Stations switch between the CCH and SCHs in each certain time interval. Thus, the CCH interval may cause very low channel utilization. To increase the CCH utilization, the HCCA TXOPs are triggered during CCH periods assuming that the HCCA TXOP will not interrupt the regular transmission of management information. The infrastructure of superframe is shown in Fig. 2.

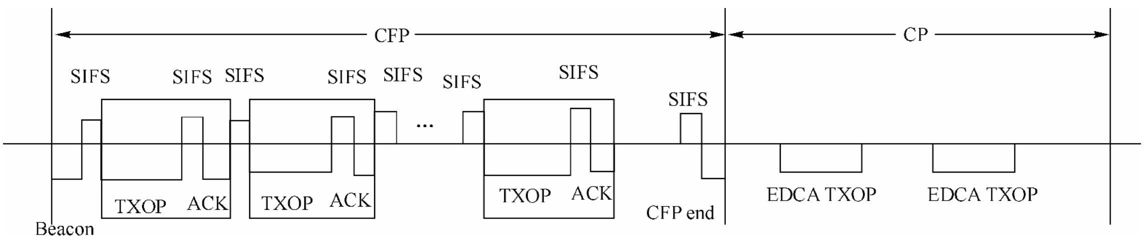


Fig. 2 Improved HCF superframe construction

3.2 Scheduling

In current IEEE 802.11e standard, the HC only schedules the recommended poll list with FIFO. The drawback of this scheduling is that some high priority requests could be processed behind the low priority requests. This, with the HCCA requirements increasing, could not satisfy the variations along with the differentiation of the TXOP requests and different access priorities. As the number of OBUs in the polling list increases, the competition of resources are more and more tensing. The optimization of scheduling is necessary. The information delivery with shorter TXOPs, higher access category or shorter deadline should be transmitted with higher priority. When an OBU sends the HCCA requirements, it calculates request's priority, required TXOP length and packet deadline. These parameters are packed into the requirement for the HC to schedule its delivery. The HC normalizes these parameters and calculates a weight for each OBU. The bigger weight may trigger a higher ranking. One OBU may send more than one requirement. And each requirement should cause a recalculation. The weight calculation is as below:

$$\omega = N_{\mathrm{AC}}\omega_{\mathrm{AC}} + N_{\mathrm{TXOP}}\omega_{\mathrm{TXOP}} + N_{\mathrm{deadline}}\omega_{\mathrm{deadline}} \tag{2}$$

where ω is the weight of certain delivery requirement item; N_{AC}, N_{TXOP}, N_{deadline} are the normalization of these parameters; ω_{AC}, ω_{TXOP}, $\omega_{\mathrm{deadline}}$ are the constant values for calculating the weight for each parameter. We tune these constant values of each parameter to get an optimal scheduling policy. In our design, ω_{AC} is set to 0.4, ω_{TXOP} is set to 0.3, and $\omega_{\mathrm{deadline}}$ is set to 0.3.

3.3 Complexity analysis

In this section, we discuss the complexity of the scheduling. Once the HC receives one HCCA requirement, it has to re-calculate the weight of each requirement item and sort the poll list before broadcast in the beacon frame. Each OBU may send more than one request in the EDCA TXOP. For each requirement, the complexity can be calculated in Eq. (3):

$$\begin{aligned} C_{\mathrm{HC}} = {} & O(R_{\mathrm{weight}}) + O(C_{\mathrm{sort}}) = \\ & O(N_{\mathrm{AC}} + N_{\mathrm{TXOP}} + N_{\mathrm{deadline}}) + O(n^2) = \\ & O(n) + O(n^2) = O(n^2) \end{aligned} \tag{3}$$

where n is the total number of nodes; $O(R_{\mathrm{weight}})$ means the complexity of the weight calculation; $O(C_{\mathrm{sort}})$ stands for the complexity of queue sorting. For each incoming HCCA requirement, the HC will first calculate the weight and then repeat the sorting. The normalization will go through n items in the poll list; the sorting algorithm is $O(n^2)$. Thus, for n OBU nodes, the calculation complexity is $O(n^2)$.

4 Simulation and evaluation

4.1 Simulation design

Several simulation experiments have been carried out to evaluate the performance of the proposed polling scheme and the scheduling algorithm. The simulation has been implemented on QualNet 4.0 platform. The computer system is CentOS5.5 with 2 GB memory. The simulation model has been designed based on the existing HCF model with ODMRP routing protocol. In the simulation, we increase the number of the HCCA requirements by including the highest AC and the second highest AC messages into the HCCA buffer at MAC layer. Both of the CCH and the SCHs intervals are set to 50 ms. The overload packages will be lost at the mobile nodes when buffer is full. The system setup consists of one RSU and 40 OBUs, the OBUs are always under the coverage of the RSU. Each OBU sends the HCCA requirements to the RSU during the SCH interval and at the same time broadcasts the scheduling results for next transmission by the EDCA scheme. Both the RSU and the OBUs are allocated in a 1 000 m highway environment. Each OBU is assumed to runs for 2 h with the speed of around 30 km/h. Traffic data is generated following normal distribution in random time interval. Since the normal coverage of a RSU is around 1 km^2, given a car running at 100 km/h, which is 27.8 m/s, the average running time in the coverage of the RSU is 36 s, which is enough for the OBUs to either transmit data or drop expired packets.

We compare the reference HCCA scheme specified in the standard and the improved scheme on the transmission delay, throughput and package loss rate. By the reference scheme, only 6~7% messages could be transmitted by the HCCA scheme, while others will be transmitted by the EDCA scheme. Therefore, the increasing of traffic load may cause a significant variation on the transmission delay and throughput. Besides, the HCCA packets are delivered in the SCHs duration, which means that the channel utilization is lower and the competition between different medium access schemes is high.

By the proposed mechanism, 10%~20% messages will be transmitted by the HCCA. Since the HCCA messages are delivered in the CCH duration, the channel utilization and throughput should be higher and the transmission delay will be lower. The deadline of each packet is set to an average value according to the packets access categories. Packets with higher AC level, shorter delivery period and closer to deadline will be set to a higher transmission priority.

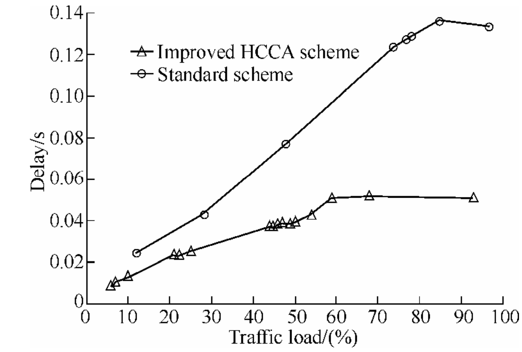
We have also compared the delay with improved scheduling and without scheduling. The performance variation becomes obvious when increasing traffic load.

4.2 Result and analysis

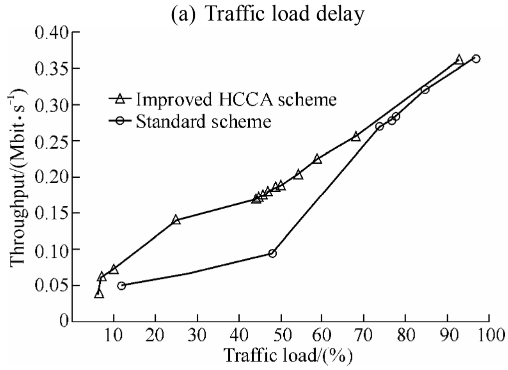
Fig. 3(a) demonstrates the delay between the HCCA scheme in the standard and the improved HCCA mechanism. Along with the traffic load increases, the differences between these two schemes are more obvious. The standard HCCA scheme shows a linear increasing of delay. When the traffic load closes to 100%, the delay is going smoothly between 0.12 s~0.14 s. While the improved HCCA scheme presents over 60% reduction compared with the standard one. By the standard scheme, the valid HCCA packets are only 6%~7% of the total HCCA packets, while the rest are fulfilled with overshooting empty feedback frames, which causes the transmission delay grow higher. By the improved scheme, the valid HCCA packets are 10% of the total number of packets and are transmitted with an alternative channel, which leaves more chances to the transmission of the EDCA packets. In this way, the channel utilization can be increased and delay will be decreased. Fig. 3(b) demonstrates the throughputs of standard HCCA scheme and the improved HCCA mechanism. When the traffic load is lower, the throughput of improved scheme is higher than the standard one. However, when the traffic load is at a higher level, the throughputs of both schemes are almost same when traffic load closes to 100%.

Fig. 3(c) compares the delays between standard scheduling and improved scheduling. The result shows that the improved scheme has almost 30% reduction over the standard scheme. When the traffic load is low, the delay of the standard scheduling scheme has a big vibration according to the queuing sequence. The improved scheduling scheme can better adjust the sequence and serve the packets with higher priority, shorter deadline and transmission period first so that the delay increases within a small range. When the traffic load grows to a high level, the difference between the standard scheme and the improved one is very clear.

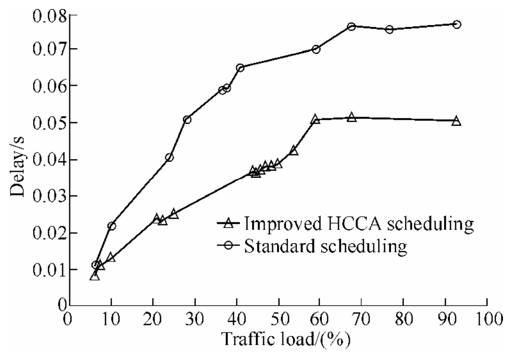
The above simulation results demonstrate that the improve HCCA mechanism with the scheduling has better performance than the standard one.



(a) Traffic load delay



(b) Traffic load throughput



(c) Traffic load delay

Fig. 3 Delay and throughput of the improved HCCA and standard HCCA

5 Conclusions

In this paper, we have improved the polling scheme specified by the IEEE 802.11p standard to improve the performance of the V2R communication. The proposed scheme can reduce the overhead generated in the polling process and adjust the recommended poll list dynamically. In addition, we have proposed an adaptive HCF scheduling algorithm with more factors such as AC, TXOP duration and packet deadline into the consideration to determine the transmission priority. We have built the simulate models to evaluate the performance of our proposal by the QualNet in a highway V2R environment. And the simulation results demonstrate that the delay and throughput are much better than those of the HCCA mechanism specified in the standard.

Acknowledgements

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