An Effective APP MAC Scheme for Multimedia WLAN-based DSRC Networks

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Abstract **– The paper proposes an effective *adaptive p-persistent-based* (APP) *medium access control* (MAC) *scheme* for WLAN-based dedicated short-range communications (DSRC) networks supporting multimedia services. The APP MAC scheme adaptively gives differentiated permission probabilities to on board units (OBUs) which are in different access category and with various waiting delay. Simulation results show that the APP MAC scheme can improve the performance of multimedia WLAN-based DSRC networks, such as small real-time packet dropping probability, low delay variation, and high system throughput, compared to conventional MAC algorithms.**

I. INTRODUCTION

The Northern American dedicated short-range communications (DSRC) standard [1] is designed to given a short to medium communication service in both road-to-vehicle communication (RVC) and inter-vehicle communication (IVC) environments. The standard can provide 27Mbps on 10MHz channel which makes it possible for various application. But the standard based on IEEE 802.11a specification uses legacy distributed coordinator function (DCF) medium access control (MAC) and it lacks support for different QoS. However, the multimedia service provisioning in future intelligent transportation systems (ITS) is crucial.

In the traditional DCF MAC to support multimedia services, dynamic contention window (CW) schemes [2-4], different maximum packet length scheme [4], and various interframe space (IFS) schemes [4-6] are usually adopted to design the priority differentiation. However, these solutions would still cause large delay variance in the same access category (AC) because of the backoff scheme. Noticeably, higher delay variance results in larger probability of quality-of-service (QoS) violation of multimedia traffic due to excess delay.

The paper proposes an *adaptive p-persistent-based* (APP) MAC scheme for the WLAN-based DSRC networks. Besides the various initial contention window (CW_{min}) and DCF interframe space (DIFS) assigned to each AC, the APP MAC scheme gives different initial permission probabilities to various ACs to further differentiate their priority. Moreover, it adaptively adjusts the permission probability of OUBs, or say stations below, in each AC according to their respective waiting delays to reduce the delay variance of stations within the same AC. Simulation results show that the APP MAC scheme can improve the performance of multimedia WLAN-based DSRC networks, such as small real-time packet dropping probability, low delay variation, and high system throughput, compared to conventional MAC algorithms.

The rest of the paper is organized as follows. Section II introduces the traditional DCF MAC. Section III describes the APP MAC scheme. Section IV illustrates the performance comparisons of the APP MAC scheme and other conventional methods, such as BEB MAC and PBA MAC, by simulation results. Finally, concluding remarks are given in section V.

II. SYSTEM MODEL

This paper considers three different priority access categories (AC): high, medium, and low priorities for WLAN-based DSRC networks. Each AC has its associated values of CW and arbitration interframe space (AIFS). A station with a new packet is allowed to transmit only if the channel is sensed idle for AIFS. Otherwise, the transmission is deferred and an exponential backoff procedure is invoked. In 802.11, the backoff procedure is implemented by using a backoff counter. During each backoff, the backoff counter is decreased whenever the channel is sensed idle for a slottime, is frozen when any packet transmission is detected, and is reactivated when the medium is sensed idle for AIFS again.

An ideal channel condition without hidden terminals and with error-free transmission is assumed. Packets generated from high priority AC stations are modeled in an on-off behavior; medium and low priority AC stations are assumed to be in the saturation mode. The number of medium (low) priority AC stations is set to be 10 (30), while the number of high priority AC stations is altered to indicate various traffic load conditions.

III. THE APP MAC SCHEME

The APP MAC scheme for WLAN-based DSRC networks *generalizes* the CSMA/CA MAC scheme with *binary exponential backoff* (BEB) algorithm for traditional WLAN when the backoff counter of a station in a backoff stage decreases to zero. At this instant, the station with the APP MAC scheme may transmit packet with a permission probability $\boldsymbol{P}$ or enter into a re-backoff procedure with a probability $(1-\boldsymbol{P})$. Here, the re-backoff procedure is defined

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as the process of that the station will remain at the same backoff stage with the same contention window. If $\boldsymbol{P}$ is equal to one, the APP MAC scheme turns to the CSMA/CA MAC scheme with BEB algorithm.

The value of the permission probability $\boldsymbol{P}$ is given an initial permission probability P_0 and is adaptively adjusted, according to the state of its packet transmission, which is a function of the number of retransmissions (backoff stages), denoted by $\boldsymbol{RT}$, and the number of re-backoffs, denoted by $\boldsymbol{RB}$. Noticeably, $\boldsymbol{RT}$ and $\boldsymbol{RB}$ can be regarded as indexes of delay time of packet transmission. If a station enters into the re-backoff procedure one time, the value of $\boldsymbol{RB}$ will be added one until up to RB_{max}, where RB_{max} is the maximum number of re-backoff times. When the value of $\boldsymbol{RB}$ is equal to RB_{max} and the station enters into the re-backoff procedure again, the value of $\boldsymbol{RB}$ will not be increased anymore. If a station suffers a collision, the value of $\boldsymbol{RT}$ will be added one until up to BS_{max}, and the value of $\boldsymbol{RB}$ will be set to zero, where BS_{max} is the maximum number of backoff stage. When the value of $\boldsymbol{RT}$ is equal to BS_{max} and the station collides again, the station will remain with the value of $\boldsymbol{RT}$ equal to BS_{max}. If a station achieves a successful transmission, values of both $\boldsymbol{RT}$ and $\boldsymbol{RB}$ will be set to zero. Consequently, the APP MAC scheme can make a station obtain a higher permission probability $\boldsymbol{P}$ at the same backoff stage if the station has a larger $\boldsymbol{RB}$; it will make a station obtain a lower permission probability $\boldsymbol{P}$ if the station is in the state with a smaller $\boldsymbol{RT}$.

More in details, for a station with the APP algorithm, $\boldsymbol{RT}$ and $\boldsymbol{RB}$ are initially zero, and $\boldsymbol{P}$ is assigned to be P_0 which is the beginning permission probability chosen for the first transmission of a ready packet. Afterwards, $\boldsymbol{P}$ will be adaptively adjusted according to the function designed by

$$\boldsymbol{P} = P_0 + \frac{1-P_0}{BS_{max}} * \left[\boldsymbol{RT} + \frac{\boldsymbol{RB}}{1+RB_{max}} \right], \quad 0 \le \boldsymbol{RT} \le BS_{\max}, \ 0 \le \boldsymbol{RB} \le RB_{\max}. \tag{1}$$

The rationale of (1) is that a station having larger $\boldsymbol{RT}$ and $\boldsymbol{RB}$ should be promoted to have a larger permission probability $\boldsymbol{P}$ in order to decrease the delay variance. Also, it is expected that the average waiting time spent at any $\boldsymbol{RB}$ for a given $\boldsymbol{RT}$ would be less than that spent at ($\boldsymbol{RT}$+1) and $\boldsymbol{RB}$ = 0. Therefore, it is reasonable that $\boldsymbol{P}$ is increased by $(1-P_0)/BS_{max}$ if one more retransmission and by $(1-P_0)/[BS_{max}*(1+RB_{max})]$ if one more re-backoff procedure.

IV. SIMULATION RESULTS

Table I lists system parameters of the considered WLAN-based DSRC environment. In the simulations, the multimedia WLAN-based DSRC networks considers three kinds of ACs: high, medium, and low priorities. High (low) priority AC is for real-time (non-real-time) service, and medium priority AC is for multimedia message service (MMS).

TABLE I Parameter settings for WLAN-based DSRC environment

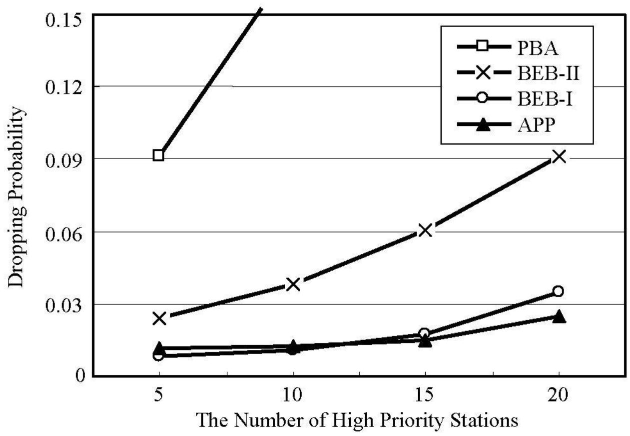
Slot time	20 μs
DIFS for high priority AC	60 μs
DIFS for medium priority AC	80 μs
DIFS for low priority AC	80 μs
SIFS	10 μs
Propagation delay	1 μs
Bit rate	11 Mbps
PHY overhead	192 μs
MAC header	28 byte
ACK length	14 byte
BS_{max}	5
RB_{max}	5
High priority AC packet payload	59 byte
Medium priority AC packet payload	528 byte
Low priority AC packet payload	1028 byte

The BEB in [7] and the priority backoff algorithm (PBA) in [2] are selected for comparison. In PBA, each station computes the average quantity, in unit of bytes, of successful transmission data of the system. When a station has packet to transmit, it calculates CW based on the average system quantity and its priority. If the quantity of successful transmission data of the station itself is higher (smaller) than the average system quantity, the station should choose a larger (smaller) CW to let other station (itself) have higher possibility to access the channel, otherwise it uses the same CW to select backoff counter.

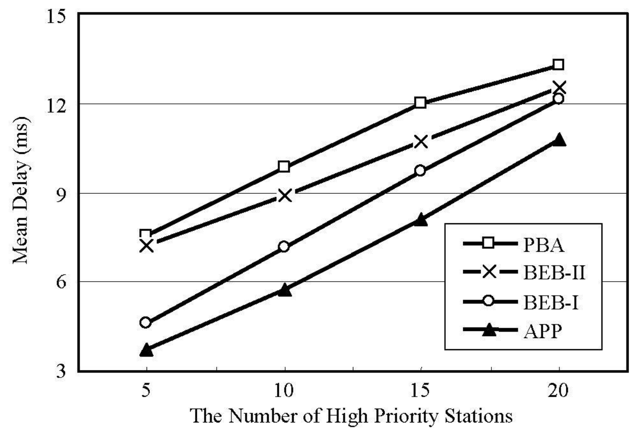
The P_0 (CW_{min}) for high, medium, and low priority AC stations in the APP MAC scheme is assumed to be 1/2 (8), 1/16 (24), and 1/32 (32), respectively. The CW_{min} of all priorities in PBA is set to be 16. The BEB with CW_{min} equal to 8, 24, and 32 (16, 24, and 32) for high, medium, and low priority AC stations, respectively, is called BEB-I (BEB-II). Define the delay time of a high-priority packet as the time elapsed between the instant of the packet generation and the instant of the packet reception. A high-priority packet will be dropped if its delay time is larger than 40 ms. Also, the QoS requirement of high-priority service is defined as the high-priority packet dropping probability, which is set to be 3%.

Fig. 1 depicts (a) dropping probability, (b) mean delay, and (c) delay variance of high-priority packets in the WLAN-based DSRC networks using APP, BEB and PBA versus the number of high priority AC stations. It can be found that the high-priority packet dropping probabilities of the APP and BEB-I schemes are much smaller than those of the BEB-II and PBA schemes. Also, under the QoS requirement of high-priority service, APP can accommodate more than 20 high-priority stations, while BEB-I, BEB-II and PBA can have 18, 7 and 0 high-priority stations, respectively. The APP performs even better than the BEB-I. The reasons are that the APP further differentiates priorities of ACs by the initial assignment of P_0, and gives high-priority service stations a largest P_0 to have a highest priority. Thus, the APP has the least mean delay, which is shown in Fig. 1 (b). Moreover, the APP has both the capability of adaptive adjustment of permission probability and the effect of re-backoff procedure. Thus the APP achieves the station's transmission delay approaching to the mean value, and it has the smallest delay variance, which is given in Fig. 1

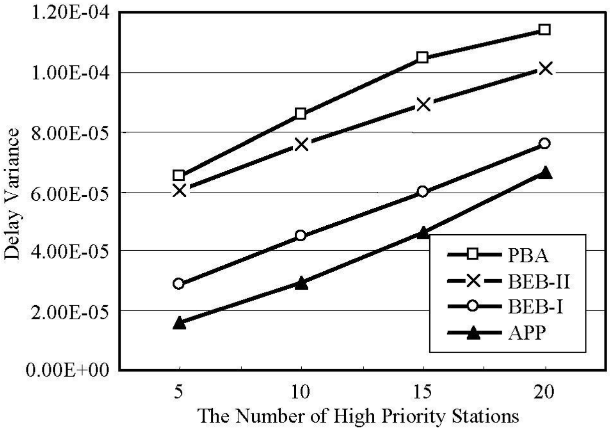
(c). On the other hand, the BEB-II cannot differentiate the priority of high-priority service from the other two ACs by CW_{min} more greatly than APP and BEB-I. Therefore, the increasing of the number of high priority stations would enlarge the collision probability of system. This causes BEB-II has higher mean delay, delay variance, and dropping probability of high-priority packets. The PBA changes CW_{min} of high priority stations without considering the number of high priority stations and the various payload size of different priority. In this simulation scenario, the payload size of high priority packet is much smaller than that of medium and low priority packets, thus the quantity of successful transmission data of high priority station is less than the average system quantity. This leads the high priority stations to change their CW_{min} to a small one and then results in a high collision probability. The phenomenon would make PBA have the highest mean delay, delay variance, and dropping probability of high-priority packets.



(a)



(b)



(c)

Figure 1 (a) Dropping probability (b) mean delay and (c) delay variance of high-priority packets

Figure 2 shows the system throughput versus the number of high priority stations. It can be seen that, APP performs the best and BEB-I performs the worst. When the number of high priority stations is 15, APP achieves an improvement of system throughput over BEB-I, BEB-II, and PBA by 24.1%, 9.9%, and 16.4%, respectively. The reasons are that the APP owns P_0 to differentiate the priority, which can reduce collision probability among stations of different priorities; the APP adaptively adjusts the permission probabilities, which can decrease collision probability among stations in the same AC. Consequently, APP enlarges the channel utilization and enhances the system throughput. Noticeably, when the number of high priority stations is larger than 18, the system throughputs of PBA and BEB-II are a little bit higher than that of APP. That is because APP devotes most of the channel bandwidth to sustain the high-priority QoS requirement, while PBA and BEB-II violate the high-priority QoS requirement, which was illustrated in Fig. 1 (a).

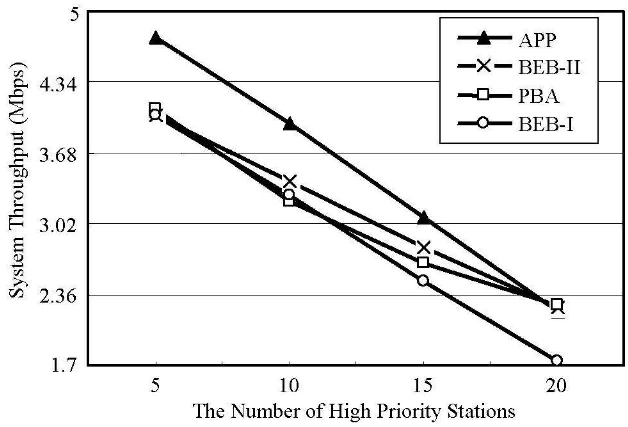
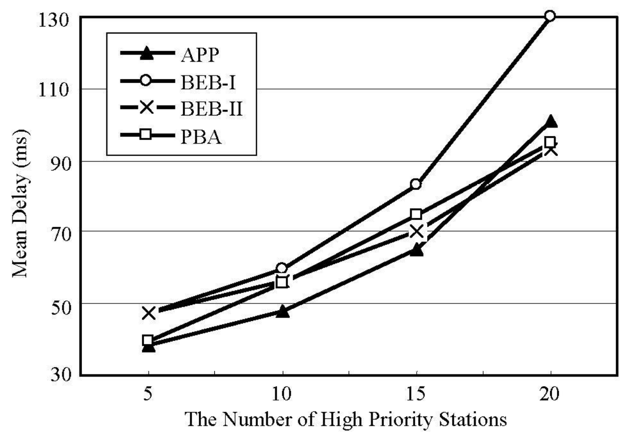
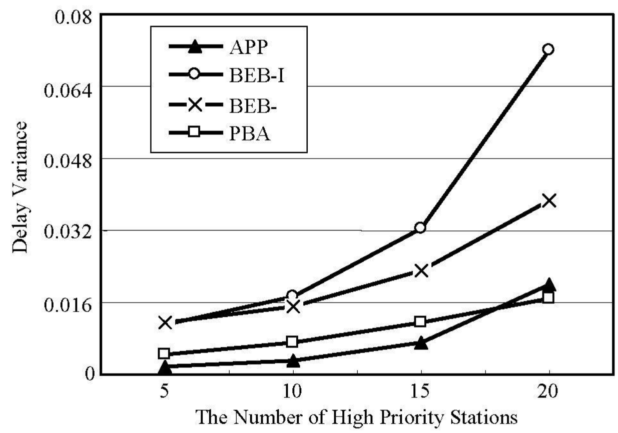


Figure 2 System throughput

Figure 3 presents (a) mean delay and (b) delay variance of medium priority packets versus the number of high priority stations. It can be found that the APP scheme has the smallest mean delay and delay variance of medium priority packet. The APP achieves an improvement of mean delay (delay variance) of medium priority packet by 21.4% (78.1%) over the BEB-I, by 7.5% (69.4%) over the BEB-II, and by 12.7% (39.3%) over the PBA, at the number of high priority stations is 15. Figure 4 presents the (a) mean delay and (b) delay variance of low priority packets versus the number of high priority stations. We can also see that the APP scheme has the smallest mean delay and delay variance. When the number of high priority stations is 15, the APP achieves by 21.6% (83.5%), by 9.6% (78.3%), and by 11.1% (16.9%) improvement of mean delay (delay variance) of low priority packet over the BEB-I, BEB-II, and PBA, respectively. The reason is that P_0 in APP provides another dimension to avoid collision and makes the transmission efficiency, this results in APP has the smallest mean delay for medium and low priority packets. Also, the permission probability adaptive adjustment and re-backoff procedure of APP in the medium and low priority stations work well, thus their delay variance is the smallest. On the other hand, the BEB-I differentiates priority more greatly by setting a smaller CW_{min} for high-priority stations than the BEB-II. This makes high-priority stations of BEB-I use a larger portion of channel bandwidth. Therefore medium and low priority stations with BEB-I cannot access the channel more probabilistically and have mean delay and delay variance higher than those with BEB-II. In PBA, the payload sizes of medium and low priority packets are large, thus the quantity of successful transmission data of medium and low priority stations are larger than system average quantity. These medium and low priority stations would change CW_{min} up to maximal contention window to reduce the collision probability of medium and low priority stations. Therefore, their delay and delay variance are smaller than those of BEB-I and BEB-II.

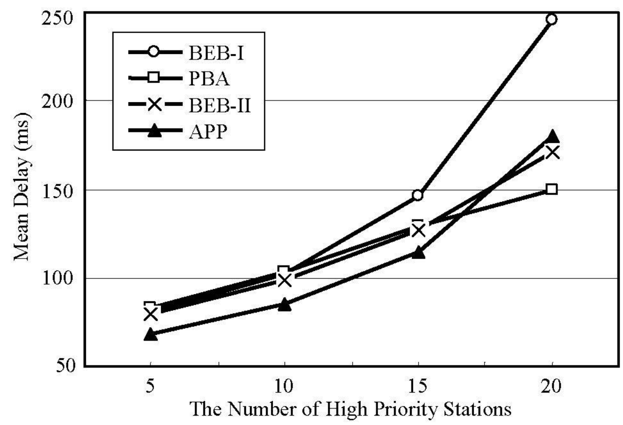


(a)

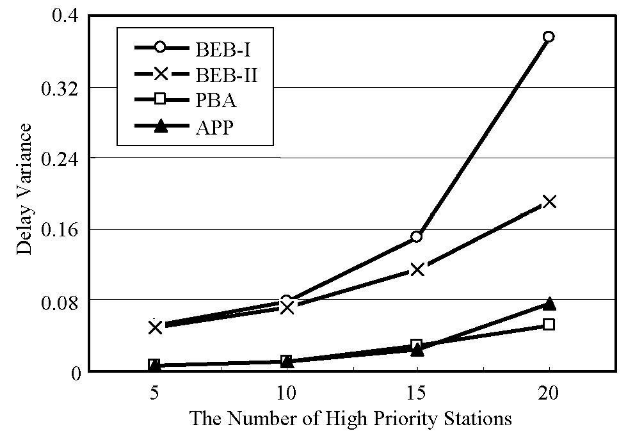


(b)

Figure 3 (a) Mean delay and (b) delay variance of medium priority packet



(a)



(b)

Figure 4 (a) Mean delay and (b) delay variance of low priority packet

V. CONCLUDING REMARKS

In this paper, an effective adaptive p-persistent (APP) MAC scheme is proposed for WLAN-based DSRC network supporting multimedia service. The APP MAC scheme can differentiate stations with various AC of services in multimedia

WLAN-based DSRC network by setting different initial permission probabilities. Also, it dynamically determines the permission probability of station in the same AC, according to its transmission state, to reduce the delay variance of station. Simulation results show that the APP MAC scheme can enhance the performance of multimedia WLAN-based DSRC network; it effectively improves the capacity of high priority stations, reduces the mean delay, enhances the mean throughput, and achieves lower delay variance, compared to conventional algorithms, for WLAN-based DSRC networks.

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REFERENCE

[1] ASTM E2213-03 - Standard specification for telecommunications and information exchange between roadside and vehicle systems - 5 GHz band dedicated short range communications (DSRC) medium access control (MAC) and physical layer (PHY) specifications, Jan. 2006.

[2] F. Cali, M. Conti, and E. Gregori, "Dynamic tuning of the IEEE 802.11 protocol to achieve a theoretical throughput limit, " *IEEE/ACM Trans. on Networking*, vol. 8, no. 6, pp. 785-799, Dec. 2000.

[3] S. Yan, Y. Zhuo, S. Wu, and W. Guo, "Priority backoff algorithm for IEEE 802.11 DCF, " *International Conference on Communications, Circuits and Systems* (ICCCAS), vol. 1, pp. 423-427, June 2004.

[4] I. Aad and C. Castelluccia, "Differentiation mechanisms for IEEE 802.11, " *IEEE INFOCOM*, vol. 1, pp. 209-218, April 2001.

[5] S. Choi, J. Del Prado, S. Mangold, and S. Shankar, "IEEE 802.11e contention-based channel access (EDCF) performance evaluation, " *IEEE ICC*, vol. 2, pp. 1151-1156, May 2003.

[6] R. G. Cheng, C. J. Chang, C. Y. Shih, and Y. S. Chen, "A new scheme to achieve weighted fairness for WLAN supporting multimedia services," accepted to be published in *IEEE Trans. Wireless Communications*.

[7] "IEEE standard for wireless LAN medium access control (MAC) and physical layer (PHY) specifications: medium access control (MAC) enhancements for quality of service (QoS)," IEEE Std 802.11e/D12.0, Nov. 2004.