An Adaptive P-Persistent MAC Scheme for Multimedia WLAN

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***Abstract*— The letter proposes an *adaptive p-persistent-based* (APP) *medium access control* (MAC) scheme for the IEEE 802.11e distributed WLAN supporting multimedia services. The APP MAC scheme adaptively gives differentiated permission probabilities to transmission stations 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, such as small voice packet dropping probability, low delay variation, and high system throughput, compared to conventional MAC algorithms.**

***Index Terms*— APP, WLAN, QoS, multimedia.**

I. INTRODUCTION

TO support multimedia services for the IEEE 802.11e WLAN, dynamic contention window (CW) schemes [1-3], different maximum packet length scheme [3], and various interframe space (IFS) schemes [3-5] 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 IEEE 802.11e multimedia WLAN. 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 priorities. Moreover, it adaptively adjusts the permission probability of stations in each AC according to their respective waiting delays to reduce the delay variance of stations within the same AC.

II. THE APP MAC SCHEME

The APP MAC scheme *generalizes* the traditional CSMA/CA MAC scheme with *binary exponential backoff* (BEB) algorithm 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 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. Afterwards, $\boldsymbol{P}$ will be adaptively adjusted according to the function designed by

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

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.

III. SIMULATION RESULTS

In the simulations, the multimedia WLAN considers three kinds of ACs: high, medium, and low priorities. High (low) priority AC is for voice (data) service, and medium priority AC

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is for multimedia message service (MMS). 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 packet payload size of high (medium, low) priority AC is 59 (528, 1028) bytes. The value of BS_{max} (RB_{max}) is 5 (5). Also, parameters of the WLAN are set as follows: slot time = 20 μs, DIFS for high (medium, low) priority AC = 60 (80, 80) μs, SIFS=10 μs, propagation delay = 1 μs, bit rate = 11 Mbps, PHY overhead = 192 μs, MAC header = 28 bytes, and ACK length = 14 bytes. Values of PHY-related parameters are referred to specifications of IEEE 802.11e [6]. 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.

The BEB in [6] 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 voice packet as the time elapsed between the instant of the packet generation and the instant of the packet reception. A voice packet will be dropped if its delay time is larger than 40 ms. Also, the QoS requirement of voice service is defined as the voice packet dropping probability, which is set to be 3%.

Fig. 1 depicts (a) dropping probability, (b) mean delay, and (c) delay variance of voice packets in APP, BEB and PBA versus the number of high priority AC stations. It can be found that the voice 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 voice service, APP can accommodate more than 20 voice stations, while BEB-I, BEB-II and PBA can have 18, 7 and 0 voice 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 voice 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 voice 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

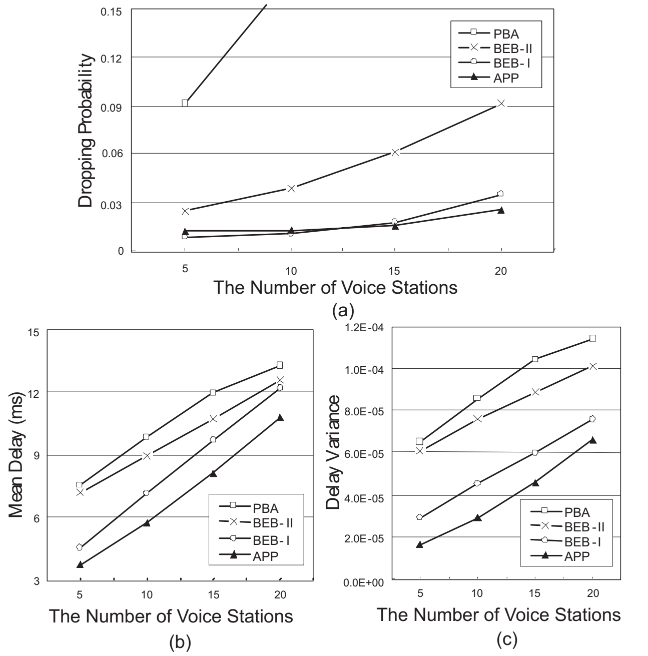

Fig. 1. (a) Dropping probability (b) mean delay and (c) delay variance of voice packets.

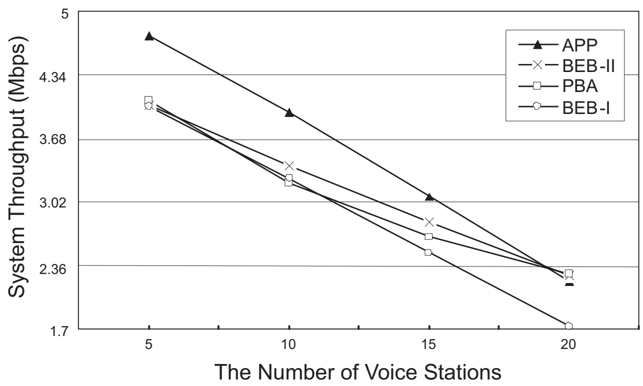

Fig. 2. System throughput.

of system. This causes BEB-II has higher mean delay, delay variance, and dropping probability of voice 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 voice (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 voice 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

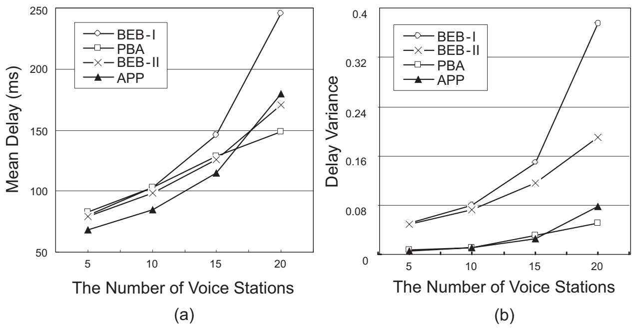

Fig. 3. (a) Mean delay and (b) delay variance of low priority packet.

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 voice QoS requirement, while PBA and BEB-II violate the voice QoS requirement, which was illustrated in Fig. 1 (a).

Figure 3 presents the (a) mean delay and (b) delay variance of low 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 low priority packet. 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. Also, these two delay measures for medium priority packets with APP, BEB-I, BEB-II, and PBA have almost the same results as those of low priority packets, which are not shown here. The reason is that P_0 in APP provides another dimension to avoid collision and makes the transmission efficiency, thus APP has the smallest mean delay for medium and low priority packets. Also, both the adaptive adjustment of permission probability and re-backoff procedure of APP for the medium and low priority stations work well, therefore their delay variance is the smallest. On the other hand, the BEB-I differentiates priority more greatly by setting a smaller CW_{min} for voice stations than the BEB-II. This makes voice 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.

IV. Concluding Remarks

In this letter, an adaptive p-persistent (APP) MAC scheme is proposed for IEEE 802.11e distributed WLAN supporting multimedia service. The APP MAC scheme can differentiate stations with various AC of services in multimedia WLAN 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; 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.

In realistic implementation, the number of re-backoffs (***RB***) and the number of retransmissions (***RT***) are statistical data recorded by station. The current CW of a station can indicate ***RT***, thus only a register is needed in the station to store the value of ***RB***. Also, the value of P_0 (RB_{max}) for an AC would be set larger (smaller) if the AC is with more delay sensitive service, for the configuration of WLAN MAC.

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