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Design and Evaluation of a Medium Access Control Scheme in Wireless Local Area Home Networks

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Abstract

Wireless Local Area Networks (WLANs) are becoming a popular way of networking computer equipments in the home and office. In order to support differentiated Quality-of-Service (QoS) in WLANs, the IEEE 802.11e Enhanced Distributed Channel Access (EDCA) protocol allocates multiple Access Categories (ACs) with different priorities, inter-frame spaces, and contention window sizes. This paper presents an improved Medium Access Control (MAC) scheme to enhance the QoS of WLANs based on the idea of using the different increasing functions for each AC to enlarge the size of contention window in the case of transmission collision. The performance of this improved scheme under multimedia applications is extensively investigated and compared with the original EDCA using the well-known network simulator NS-2. The results show that this scheme is able to achieve higher throughput and medium utilization as well as lower access delay and packet loss probability than the original EDCA. Moreover, it provides a good prioritization level between multiple ACs.

1. Introduction

Recently there has been a growing need for the in-home networks to supports a wide rang of digital and multimedia communication services. With such networks, the home residents can conveniently enjoy various home entertainments, such as watching TV, listening music, and making phone calls, through invisible and virtual interactions between residents and the home server. Wireless Local Area Networks (WLANs) are becoming a popular way of networking computer equipments in the home and office. The desirable properties of WLANs, such as easy deployment, flexibility, and location-independent accessibility, make them recognized as a general-purpose connectivity between computation and communication devices using waves rather than a cable infrastructure in a wide range of business organizations and home networks all over the world [10, 25]. To support the ever-growing wireless and mobile applications, the Institute of Electrical and Electronics Engineers (IEEE) ratified 802.11 standards that can operate at data rates up to 2 Mbps in the 2.4-GHz Industrial, Scientific and Medical (ISM) band. Such low data rates of the legacy IEEE 802.11 standard are unable to support the general requirements of business communication. Recognizing the critical need to support higher data-transmission rates, the IEEE have further ratified both 802.11a and 802.11b standards with the rates up to 54 and 11 Mbps in 5 and 2.4-GHz ISM band, respectively [10]. Moreover, both standards specify the specification of the Medium Access Control (MAC) protocol, which is responsible for control access to the scarce transmission medium and for enabling its capacity to be fully utilized in an efficient manner by wireless network devices.

The dominating mechanism of the IEEE 802.11 MAC is called the Distributed Coordination Function (DCF), which relies on the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) algorithm to access the shared medium. The DCF mechanism makes certain that the stations sense the medium prior to data-transmission. Moreover, it applies a Collision Avoidance (CA) mechanism which can reduce the collision probability by virtue of an additional random binary exponential time named back-off time. The main objective of CSMA/CA is to avoid stations transmitting packets at the same time, which can lead to collisions and corresponding retransmissions [3, 10, 15, 25]. Moreover, the DCF further reduces the collision possibility and improves the system reliability by adding the acknowledgement frames and optional channel reservation frames (i.e., Request-To-Send and Clear-To-Send) to the exchange sequences of its data frames.

With the increasing demand of wireless services, the provisioning of differentiated Quality-of-Service (QoS) has become a critical issue of the future wireless multimedia communications. Therefore, it is important to develop the medium access schemes that can support real-time multimedia applications with the differentiated QoS constraints. As a result, the IEEE 802.11 working group has recently standardized an extended version (IEEE 802.11e) that defines the Enhanced Distributed Channel Access (EDCA) protocol for the support of QoS differentiation [26]. EDCA delivers the frames based on their differentiated Access Categories (ACs), which can be achieved by varying the amount of time when a station senses the channel to be idle before the start of the back-off procedure, or the length of the contention window, or the duration during which a station can transmit data after occupying the channel [26]. The stations with the lower-priority AC must wait longer than those with the high-priority AC before they are able to access the medium.

The studies on design and evaluation of IEEE 802.11e MAC protocols have attracted numerous research interests and efforts [6, 7, 16, 24]. For instance, Gannoune [7] has proposed a non-linear dynamic scheme for tuning the minimum contention windows to enhance service differentiation. Mangold et al. [16] have evaluated the performance of IEEE 802.11e EDCA in the single and overlapping Access Point (AP) environments using the traffic models with negative-exponentially distributed inter-arrival times. They have focused on the analysis of the effectiveness and limitations of EDCA in such environments. Zuh et al. [24] have introduced the dual-measurement technique to vary the size of contention window according to the traffic state of each AC, which can improve the throughput, mean access delay and medium utilization of wireless ad-hoc networks with the EDCA MAC protocol. Moreover, Frikha et al. [6] have proposed a slow decrease scheme to tune the minimum contention windows in the congested environments.

The key aim of these existing studies is to identify the appropriate contention window for each AC in order to achieve good system performance. Actually, the use of a large contention window may reduce the number of transmission collisions. On the other hand, it increases the back-off time dramatically. However, choosing a small contention window for the highest priority AC can increase the number of collisions, especially when the system works under the heavy loads. In order to enhance the QoS of WLANs, this paper presents an improved and cost-efficient MAC scheme where the different ACs are assigned with the identical minimal/maximal contention windows ($cw_{\min}$, $cw_{\max}$). However, the differentiated Arbitration Inter-Frame Space (AIFSs) and various increasing functions (i.e., linear, logarithmic, exponential and quadratic functions) are used to increase the contention windows of different ACs in the case of transmission collision. This scheme can alleviate the increasing number of collisions caused by the small contention window of the highest AC and improve the prioritization behaviour of the existing EDCA.

Moreover, this study uses the network simulator NS-2 to investigate the performance of the proposed MAC scheme and compare it to the original EDCA in the presence of wireless multimedia in-home applications. For this purpose, the non-bursty Poisson, bursty ON/OFF, and fractal-like self-similar processes with high variability are used to model and generate heterogeneous background, voice, and Variable-Bit-Rate (VBR) video traffic. The performance results reveal that the improved scheme performs better than the original EDCA in terms of throughput, access delay, medium utilization and packet loss probability. Additionally, it can support prioritization between different ACs at a good level.

The rest of the paper is organized as follows: Section 2 introduces the existing MAC schemes for WLANS including the IEEE 802.11 DCF and IEEE 802.11e EDCA. Section 3 proposes the improved MAC scheme. Section 4 presents and analyses the performance results obtained from simulation experiments. Finally, Section 5 concludes this study.

2. Existing Medium Access Control (MAC) Schemes

This section starts with an introduction to the traditional IEEE 802.11 DCF scheme, and then presents the QoS differentiation mechanism of the IEEE 802.11e EDCA scheme.

2.1 Distributed Coordination Function (DCF)

The contention-based DCF is the basic access mechanism of IEEE 802.11. Like most of the other contention-based MAC protocols, DCF relies on a Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) algorithm to access the shared medium. A station having packets ready for transmission senses whether or not the medium is busy. If it has been idle for longer than the minimum duration called DCF Interference Space (DIFS), the station can start transmission immediately. Otherwise a back-off time is chosen randomly from the interval $[0, cw]$, where cw represents the contention window [20]. The stations start down-counting its back-off counter by one only if the medium has been detected idle for at least a DIFS. If the medium gets busy due to other transmissions, the back-off counter pauses down-counting and resumes when the medium has been sensed idle for DIFS again [11,20]. Transmission may proceed when back-off counter has reached zero. Upon detection of a collision, i.e., after the back-off counter of two or more stations reach zero at the same time, the contention window is doubled according to $cw_i = 2^{k+i-1} - 1$ where i is number of attempts to transmit the frame and k is a constant defining the minimum contention window $cw_{\min} = 2^k - 1$ [10]. When the destination station receives frame successfully, it sends an acknowledgment (ACK) frame back to the source station after a Short Inter frame Space (SIFS) duration. Additionally, to alleviate the hidden station problem, DCF uses optional Request-to-Send/Clear-to-Send (RTS/CTS) frames prior to packet transmission [25]. A station initiates the transmission process by sending an RTS frame. The destination station replies to the RTS frame with a CTS frame to confirm the reservation of the shared medium. After that, the source station transmits a data packet to the destination station. This process is illustrated in Figure 1.

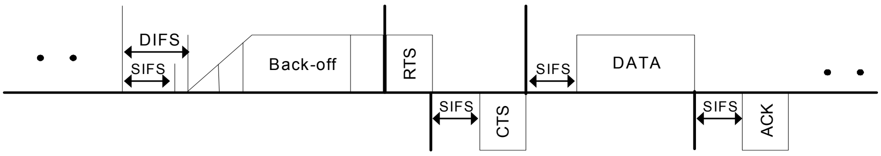

Figure 1. RTS/CTS of IEEE 802.11 DCF

2.2 Enhanced Distributed Channel Access (EDCA)

The IEEE 802.11 DCF has no functionality to support QoS requirements of multimedia applications due to its contention-based mechanism. To overcome the drawback of the traditional DCF, EDCA has been proposed to provide differentiated and distributed channel accesses for four different Access Categories (ACs). Each AC has its own transmission queue and is labeled corresponding to the category of the applications, i.e. AC_VO (voice), AC_VI (video), AC_BE (best- effort), and AC_BK (background), as shown in Figure 2.

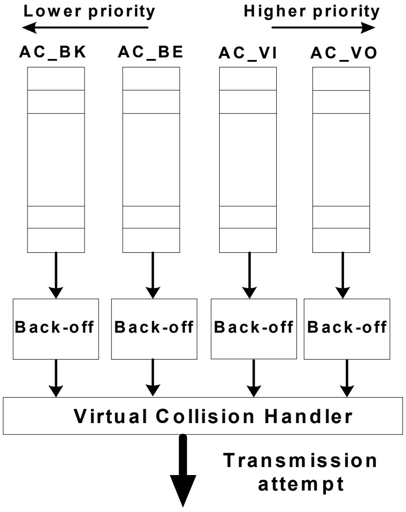

Figure 2. IEEE 802.11e MAC transmission queue

Figure 3 reveals how individual AC contends to access the medium. These ACs are differentiated by various Inter-Frame Space (AIFS) values, Transmission Opportunity (TXOP) limits and minimal/maximal contention windows ($cw_{\min}$, $cw_{\max}$) [16, 17]. Choosing a small contention window causes the station to gain priority over others with the larger contention window. After experiencing any unsuccessful transmission, the new cw is calculated as follows

$$new\_cw[AC] >= ((old\_cw[AC]+1) * Pf[AC]) - 1)$$

where $Pf[AC]$ is the Persistence Factor that determines the degree in increase of the cw in the event of collisions. Higher priority AC has smaller $Pf[AC]$ value.

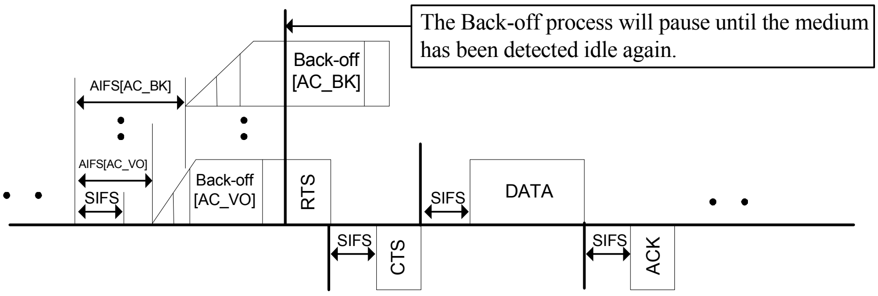

Figure 3. RTS/CTS of IEEE 802.11e EDCA

3. The Improved MAC Scheme

The performance of the current contention-based MAC protocols suffers from two major factors: (1) the large number of transmission collisions and (2) the wasted time caused by the back-off procedure. The number of collisions is tightly coupled with the size of contention window. The use of a large contention window can reduce the number of collisions. On the other hand, it increases the back-off time dramatically.

In the original IEEE 802.11e EDCA protocol, various sizes of contention window have been assigned to different ACs. In particular, when the network loads are low, the use of a large contention window for the low-priority ACs can significantly increase the back-off time and thus degrade the network performance.

Table 1. The increasing functions used by the improved MAC scheme

AC	Increasing Function
AC_VO	$new\_cw[AC] = (old\_cw[AC] + 10)$
AC_VI	$new\_cw[AC] = (old\_cw[AC] * \log(old\_cw[AC]))$
AC_BE	$new\_cw[AC] = (old\_cw[AC] * 2)$
AC_BK	$new\_cw[AC] = (old\_cw[AC])^2$

In this study, we propose an improved MAC scheme where the different ACs are assigned with the identical minimal/maximal contention windows ($cw_{\min}, cw_{\max}$).

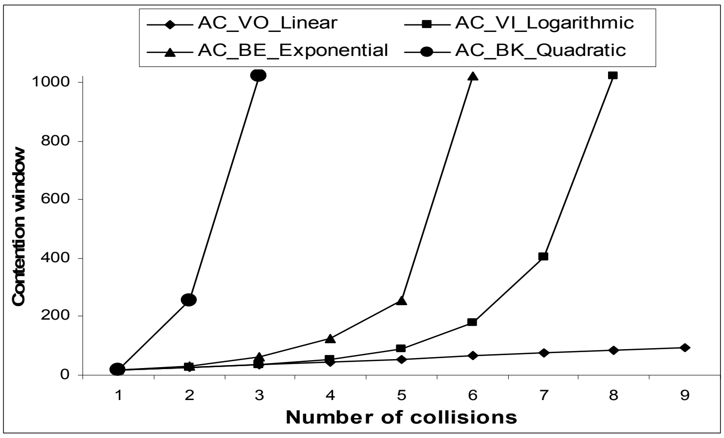

Figure 4. Behavior of different increasing functions

However, the different AIFSs and various increasing functions used to enlarge the contention windows of different ACs in the case of transmission collision are adopted to support differentiated QoS. As shown in Table 1, the slowest-increasing linear function is used for voice traffic (AC_VO) which has the highest priority. The logarithmic, exponential, and quadratic increasing functions are adopted for video (AC_VI), best-effort (AC_BE), and background (AC_BK) traffic, respectively. Figure 4 depicts the increasing behaviour of these functions as the number of collisions increases. The algorithm of increasing the contention window of different ACs is described in Figure 5.

```
Initialization:
Function CW_Initialization(AC)
   cw[AC] = cw_min;
End Function
After a successful transmission:
Function CW_Rest(AC)
    cw[AC] = cw_min;
End Function
After any collision :
Function CW_Increment (AC)
Case (AC)
case AC_VO:
      cw[AC] = cw[AC] + 10;
      break;
case AC_VI:
      cw[AC] = cw[AC] *log(cw[AC]) ;
      break;
case AC_BE:
      cw[AC] = cw[AC] * 2;
      break;
case AC_BK:
      cw[AC] = $(cw[AC])^2$;
      break;
End Case
IF  cw[AC] > cw_max THEN
  cw[AC] = cw_max;
End IF
End Function
```

Figure 5. Back-off algorithm of the improved MAC scheme

4. Performance Evaluation and Comparison

4.1 Simulation Scenarios

The improved MAC scheme has been implemented using the well-known network simulator NS-2 and its wireless extensions developed by TKN [23]. The simulation scenarios were designed to investigate the performance of this scheme in the WLAN of the in-home network.

As illustrated in Figure 6, the scenarios are composed of up to 20 mobile stations and an access point serving as a traffic sink. Each wireless station operates under the IEEE 802.11a standard at the data rate of 24Mbps [17].

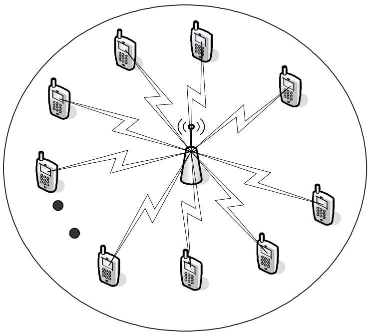

Figure 6. AP with mobile stations.

Table 2. PHY parameters for simulation scenarios

SlotTime	9 μs
CCATime	3 μs
RxTxTurnaroundTime	2 μs
SIFSTime	16 μs
PreambleLength	96 bits
PLCPHeaderLength	40 bits
PLCPDataRate	6 Mbps

The setting of physical layer (PHY) parameters is shown in Table 2; these parameters have been widely used by other performance studies on WLANs [16, 17, 23]. All stations are located within a Basic Service Set (BSS) such that every station is able to detect the transmission from others.

4.2 Heterogeneous Traffic Models

Due to the multiple services supported in multimedia home WLANs , we adopt the heterogeneous traffic models to capture the characteristics of multimedia applications. Each station involves four ACs (i.e., voice, real-time video, best-effort video, and background). The priorities of voice, real-time video, best-effort video, and background traffic follow a descending order. Table 3 lists the parameters of $cw_{\min}$, $cw_{\max}$ and $AIFS$ of the four ACs used in the improved MAC scheme and the original EDCA protocol, respectively.

Table 3. Parameters of the EDCA protocol and improved MAC scheme

EDCA	parameters	AC_VO	AC_VI	AC_BE	AC_BK
	AIFS	2	2	3	7
	$cw_{\min}$	3	7	15	15
	$cw_{\max}$	7	15	1023	1023
Improved MAC scheme	AIFS	2	2	7	7
	$cw_{\min}$	15			
	$cw_{\max}$	1023			

4.2.1 Poisson Traffic Model: Each station generates the background data packets according to a Poisson arrival process, which is characterized by the independent exponentially-distributed inter-arrival times with the rate of 160 Kbit/s and packet size of 200 bytes [16, 17].

4.2.2 Bursty ON/OFF Traffic Model: The highest priority traffic (generated by voice sources) is modelled by the bursty ON/OFF process. In general, the talkspurt and silence durations of voice ON/OFF process follow an exponential distribution with the mean of 1s and 1.35s [5], respectively. During the talkspurts period, each source generates the packets with the size of 80 bytes, corresponding to a constant sending rate of 64 Kbit/s. Given that each station may involve multiple voice sources, we consider that there are five voice sources at each station.

4.2.3 Self-Similar Traffic Model: Traffic generated by the streaming applications such as real-time and best-effort non-real-time video is modelled by self-similar processes. According to the measurement results of Star Wars video trace [3, 4], each station generates real-time and best-effort video traffic with the rate of 360 Kbit/s and Hurst parameter of 0.7. Such traffic can be generated by the superposition of many ON/OFF sources in which the ON and OFF periods follow Pareto distributions (i.e., with high variability or infinite variance) [18]. The lengths of the ON and OFF periods are determined by $K(x^{-1/a}-1)$ where x is a uniformly distributed random number between 0 and 1, $a=3-2H$, $K=m(a-1)$ and m is the mean length of ON and OFF period, respectively [13]. In the simulation experiments, we used the superposition of five Pareto-distributed ON/OFF flows with the mean ON period of 10ms and OFF period of 100ms to generate video traffic.

4.3 Performance Results

The simulation experiments aim to investigate the performance of the improved MAC scheme in the IEEE 802.11e WLANs in terms of throughput, access delay, medium utilization and packet loss probability in the presence of heterogeneous traffic. The average throughput is calculated as the amount of data actually delivered to the destination during each time unit. Many factors affect the throughput, including the efficiency of collision avoidance, medium utilization, latency, and control overhead. The access delay is defined as the time elapsed from the arrival of a packet from the higher layer to the MAC layer until the start of the successful transmission on wireless medium. We measure the access delay to find out how well the MAC scheme accommodates real-time traffic, especially the voice and video traffic. Medium utilization is referred to the percentage of time that is used for successful transmission. Moreover, packet loss probability is calculated as the ratio of the number of lost packets over the total number of generated packets.

4.3.1 Throughput: In this subsection, we evaluate the throughput of the improved MAC scheme and the original EDCA protocol. As shown in Figures 7 and 8, for the highest priority voice traffic, the throughput of the improved scheme is higher than the original EDCA. This is because the contention window of the highest priority traffic in the EDCA protocol is relatively small, leading to the increasing number of collisions and directly affects the throughput. As a result, choosing a small contention window could increase the number of collisions and degrade the system throughput.

It is also clear that the throughput of the voice traffic with the improved MAC scheme is significantly higher than the original EDCA. For example, when there are 16 active stations the throughput of the voice traffic is around 1.9 Mbit/s when the improved scheme is used and around 1.0 Mbit/s when the original EDCA is used, respectively. Compared to the original EDCA, the improved scheme achieves better throughput of the real-time video as well. Figures 7 and 8 reveal that the throughput of the real-time video with the improved scheme is higher than that of the original EDCA under all cases. Although the same minimum contention window is used for the voice and real-time video traffic, the improved MAC scheme could still keep a good prioritization level between them. This is because that this scheme adopts different increasing functions.

We can also observe from the figures that the improved scheme achieves the better throughput than the original EDCA for the best-effort video and background traffic. As a result, this new scheme can achieve the higher throughput than the original EDCA for all ACs, especially for the voice and real-time video traffic. In addition, it keeps the prioritization among all ACs at a good level. Moreover, by simply adding the throughput of each traffic category, it is easy to observe that the improved MAC scheme has a much higher system throughput than the original EDCA.

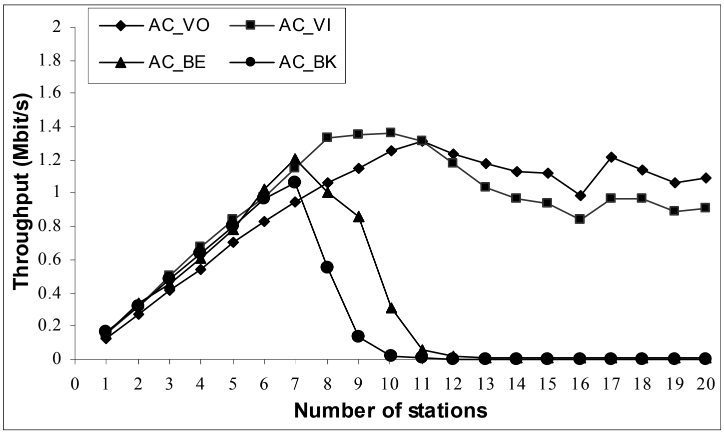

Figure 7. Throughput of the EDCA protocol

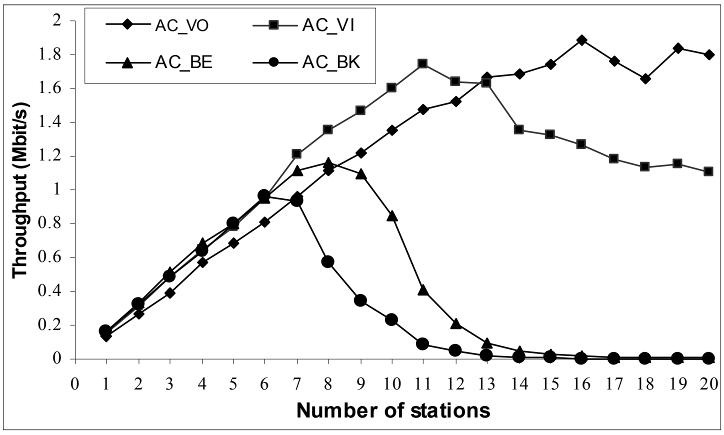

Figure 8. Throughput of the improved MAC Scheme

4.3.2 Access Delay: Figures 9 and 10 show the mean access delay for all ACs as a function of the traffic loads for the improved MAC scheme and the original EDCA, respectively. The average access delay of the voice traffic improves significantly when the improved scheme is used. In general, the improved scheme maintains around 50% lower of the mean access delay than the original EDCA for the voice traffic. As shown in the figures, the mean access delay of the real-time video traffic with the improved scheme is lower than that of the EDCA when the number of active stations is less than 17.

After this point, the improved scheme has the same access delay as the original EDCA for the real-time video. This is due to the increasing demand of bandwidth by the highest priority voice traffic. Moreover, the improved scheme can support 1 and 2 more stations for the background and best-effort video traffic, respectively, compared to the original EDCA protocol before the delay becomes infinity. To summarize, the improved scheme has a better performance than the original EDCA in terms of access delay because of the suitable contention window selected by the improved scheme.

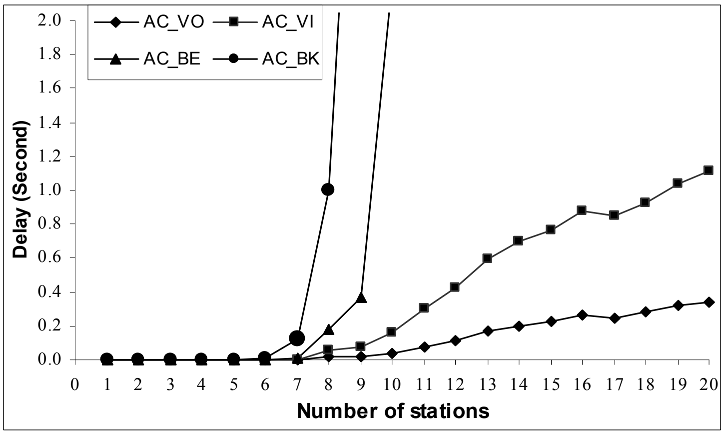

Figure 9. Mean access delay of the EDCA protocol

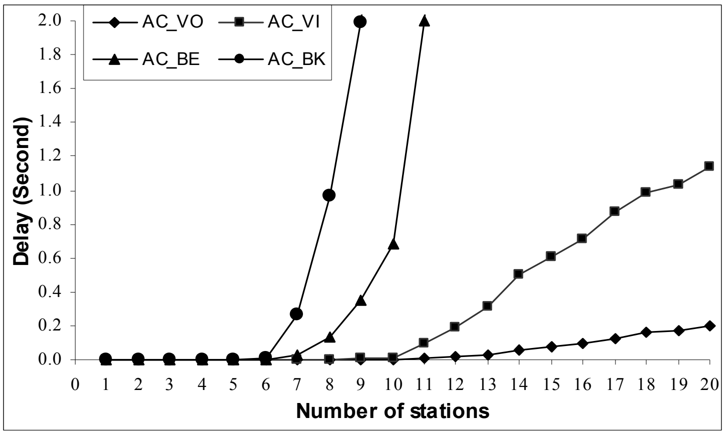

Figure 10. Mean access delay of the improved MAC scheme

4.3.3 Medium Utilization*:* In addition to throughput and access delay, Figures 11 and 12 compare the medium utilization of the improved MAC scheme and the original EDCA protocol. It is evident that the improved scheme usually has the higher medium utilization than the original EDCA. This is because the EDCA suffers from a large number of collisions due to the relatively small contention windows used for the voice and real-time video. As a result, the improved scheme can reduce the number of collisions and maintain a higher medium utilization than the original EDCA. It is also clear that, under the heavy offered loads (i.e. when there are more than 12 active stations); the medium utilization of the voice traffic is 35% higher in the improved scheme than that of the EDCA protocol. Furthermore, the improved scheme can maintain the better utilization for other ACs than the original EDCA. For example, the medium utilization of the real-time video with the improved scheme is around 11% while it is around 8% with the EDCA protocol when there are 12 active stations.

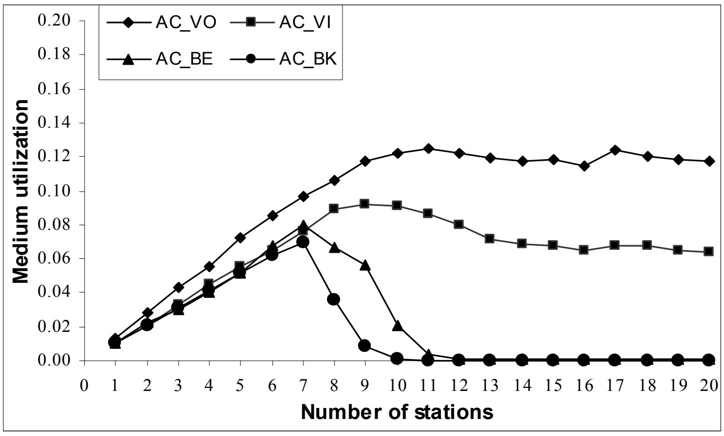

Figure 11. Medium utilization of the EDCA protocol

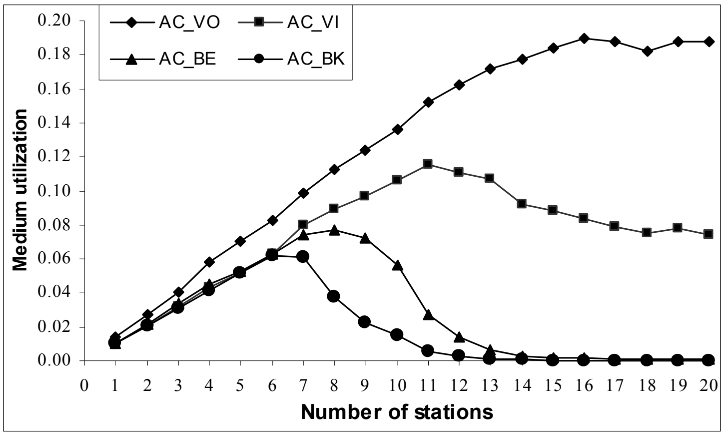

Figure 12. Medium utilization of the Improved MAC scheme

4.3.4 Packet Loss Probability: Figures 13 and 14 compare the packet loss probability of the improved MAC scheme and the original EDCA protocol. We can observe that no packet is lost until there are 6 active stations for both schemes. Beyond this point, the packet loss probability of background traffic increases dramatically. This is because the queue of background traffic becomes full due to the rare transmission opportunity awarded to such traffic. As a result, the admission control and congestion control algorithms are necessary to control the sending rate of background traffic in order to avoid the high loss probabilities. This phenomenon is due to the increasing number of collisions and the limited capacity of the transmission queues which cannot accommodate more packets. Moreover, the improved MAC scheme has lower packet loss probability for voice and real-time video traffic than that of the original EDCA protocol. More specifically, when there are 20 active stations the packet loss probability of voice traffic is around 0.3 (for the improved MAC scheme) and around 0.6 (for the original EDCA), respectively. As a result, the improved MAC scheme has a better performance than the EDCA protocol in terms of the packet loss probability in most cases especially for the voice and real-time video traffic.

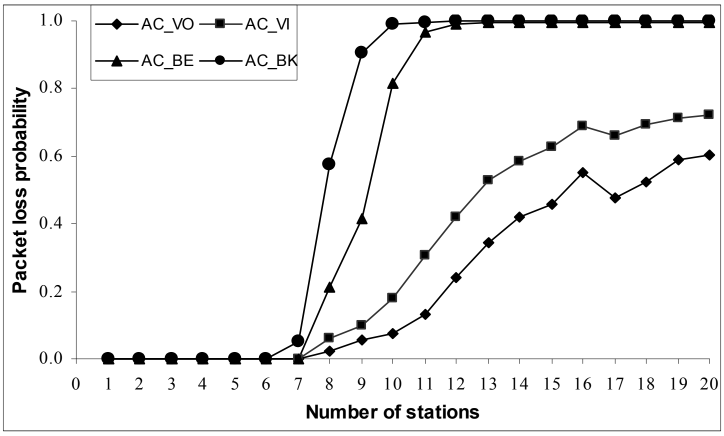

Figure 13. Packet loss probability of the EDCA protocol

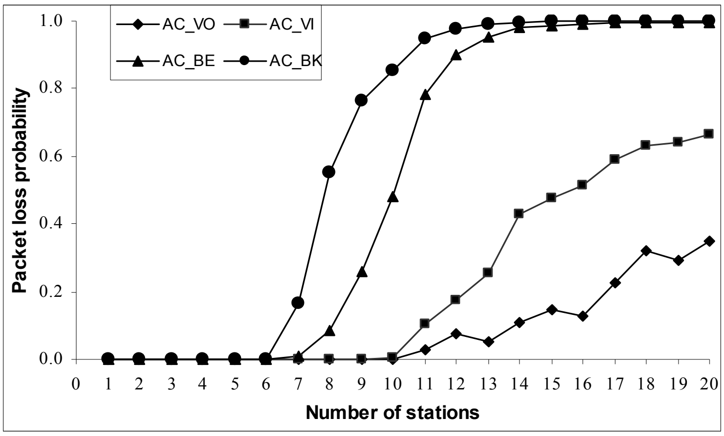

Figure 14. Packet loss probability of the Improved MAC scheme

5. Conclusions

The provisioning of differentiated QoS in multimedia WLANs is a challenging research issue. The key contributions of this paper are twofold: (1) proposing an improved MAC scheme in order to enhance the performance and service differentiation of WLANs with in-home multimedia applications; (2) conducting the extensive performance evaluation of the proposed scheme using the well-known network simulator NS-2. To capture the diverse nature of the multiple services, the WLANs are subject to the heterogeneous non-bursty Poisson, bursty ON/OFF, and self-similar traffic generated by wireless multimedia applications.

Performance results have shown that the improved MAC scheme outperforms the original EDCA in terms of throughput, mean access delay, medium utilization and packet loss probability. More specifically, under the high system loads, the throughput of the highest-priority voice traffic increases up to 36%, the medium utilization increases 49%, the access delay decreases 50%, and the packet loss probability decreases 50%. Moreover, this scheme also performs better for other ACs than the original EDCA protocol in most cases. Therefore, the proposed scheme can improve the system throughput and medium utilization as well as reduce the access delay and packet loss probability compared to the original EDCA. Moreover, this scheme keeps the prioritization between different ACs at a good level.

6. References

[1] J. Beran, R. Sherman, M.S. Taqqu, and W. Willinger, Long-range dependence in variable-bit-rate video traffic, *IEEE Trans. Communications*, vol. 43, no. 234, 1995, pp. 1566-1579.

[2] S. Byun, S. Lee, and S. Park, Performance compensation of IEEE 802.11e QoS stations with coexistence of legacy 802.11 stations**,** Proc. 9th International Conference on Advanced Communication Technology (ICACT'2007), vol.1, 2007, pp. 18-22.

[3] S. Choi, J. D. Prado, S. Shankar, and S. Mangold, IEEE 802.11e Contention-based channel access (EDCF) performance evaluation, Proc. IEEE Information and Communication Conference (ICC'2003) , vol. 2, 2003, pp. 1151-1156.

[4] B. Chen, Z. Lucic, and L. Trajkovic, Simulation and wavelet analysis of packet traffic, http://www.ensc.sfu.ca/people/ faculty/ljilja/cnl/pdf/bruce_asi2002.pdf, 2005.

[5] R. Cox, Three new speech coder from the ITU cover a range of applications, IEEE Communication Magazine, vol. 35, no. 9, 1997, pp. 40-47.

[6] M. Frikha, F.B. Said, L. Maalej, and F. Tabbana, Enhancing IEEE 802.11e standard in congested environments, Proc. Advanced International Conference on Telecommunications and International Conference on Internet and Web Applications and Services (AICT-ICIW'2006), 2006, pp. 78-82.

[7] L. Gannoune, A non-linear dynamic tuning of the minimum contention window (CWmin) for enhanced service differentiation in IEEE 802.11 ad-hoc networks, Proc. Vehicular Technology Conference (VTC'2006), 2006, pp. 1266-1271.

[8] D. Gao, J. Cai, P. Bao, and Z. He, MPEG-4 video streaming quality evaluation in IEEE 802.11e WLANs, Proc. IEEE International Conference on Image Processing (ICIP'2005), vol. 1, 2005, pp. 197-200.

[9] M. Garrett, and W. Willinger, Analysis, modelling and generation of self-similar VBR video traffic, Proc. Conference on Communications Architectures, Protocols and Applications, (SIGCOMM'1994), 1994, pp. 269-280.

[10] M. Gast, 802.11 wireless networks: the definitive guide, vol.1, O'Reilly, 2002.

[11] A. Grilo, and M. Nunes, Performance evaluation of IEEE 802.11e Proc. 13th IEEE International Symposium, Personal, Indoor and Mobile Radio Communications (PIMRC'2002), vol. 1, 2002, pp. 511-517.

[12] A. Guchhait, R. Muralidhar, and A. Bakre, Performance of Real-Time Traffic in EDCA-BASED IEEE 802.11 b/g WLANS, Proc. First International Conference on Communication System Software and Middleware (COMSWARE'2006), 2006, pp. 1-7.

[13] M. Hassan, and R. Jain, High performance TCP/IP networking concepts, issues and solutions. Pearson Prentice Hall, 2004.

[14] C. Huang, and W. Liao, Throughput and delay performance of IEEE 802.11e enhanced distributed channel access (EDCA) under saturation condition, IEEE Trans. Wireless Communications, vol. 6, no.1, 2007, pp. 136 -145.

[15] A. Lindgren, A. Almquist, and O. Schelen, Evaluation of quality of service schemes for IEEE 802.11 wireless LANs, Proc. 26th Annual IEEE Conference on Local Computer Networks (LCN'2001), 2001, pp. 348 – 351.

[16] S. Mangold, S. Choi, G. Hiertz, O. Klein, and B. Walke, Analysis of IEEE 802.11e for QoS support in wireless LANs, IEEE Wireless Communications, vol. 10, no. 6, 2003, pp. 40–50.

[17] S. Mangold, S. Choi, Peter May, O. Klein, G. Hiertz, and L. Stibor, IEEE 802.11e wireless LAN for quality of service, Proc. European Wireless Conference (EW'2002), Italy, 2002.

[18] V. Paxson, and S. Floyd, Wide-area traffic: the failure of poisson modeling, IEEE/ACM transaction on networking, vol. 3, no. 3, 1995, pp. 226-244.

[19] N. Qiang, Performance analysis and enhancements for IEEE 802.11e wireless networks, IEEE Network Magazine, vol. 19, no. 4, 2005, pp. 21-27.

[20] Z. Tao, and S. Panwar, Throughput and delay analysis for the IEEE 802.11e enhanced distributed channel access, IEEE Trans. Communications, vol. 54, no. 4, 2006, pp. 596-603.

[21] O. Tickoo, and B. Sikdar, On the impact of IEEE 802.11 MAC on traffic characteristics, IEEE Journal on Selected Areas in Communications, vol. 21, no. 2, 2003, pp. 189-203.

[22] H. L. Truong, and G. Vannuccini, Performance evaluation of the QoS enhanced IEEE 802.11e MAC layer, Proc. 57th IEEE Semi-annual, Vehicular Technology Conference (VTC'2003), vol.2, 2003, pp. 940-944.

[23] S. Wietholter, and C. Hoene, Design and verification of an IEEE 802.11e EDCF simulation model in NS-2.26, technical report TKN-03-019, Telecommunication Networks Group, Technical University Berlin, November, 2003.

[24] H. Zhu, G. Cao, A. Yener, and A.D. Mathias, EDCF-DM: a novel enhanced distributed coordination function for wireless ad hoc networks, Proc. IEEE International Conference on Communications (ICC'2004), vol.7, 2004, pp. 3886- 3890.

[25] IEEE WG 802.11, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, ISO/IEC 8802-11:1999(E), IEEE Standards 802.11, 1999.

[26] IEEE WG 802.11, Part 11: Wireless LAN Medium Access Control (MAC) and Physical layer (PHY) specifications, Amendment 8: Medium Access Control (MAC) Quality of Service Enhancements, IEEE Standards 802.11e, 2005.

[27] Executive Briefing: Wireless Network Security, www.docs.hp.com, 2006.

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