Performance Analysis of Optimum Scheme for IEEE 802.11e EDCAF

Bih-Hwang Lee and Hui-Cheng Lai
Department of Electrical Engineering
National Taiwan University of Science and Technology
lee@ccg. ee. ntust. edu. tw

ABSTRACT

In order to achieve the prioritized QoS guarantee, the IEEE 802.11e EDCAF provides the service differentiation through configuring the different QoS parameters (AIFSN, CW_{min}, CW_{max}, TXOP_limit and PF). This paper presents a simulation analysis of the influence of the AIFSN and CW_{min} parameters on the IEEE 802.11 networks and proposes a simple optimum scheme which is based on different traffic classes and QoS requirement to improve the WLAN performance. Our algorithm is simple and effective in managing QoS WLAN networks. The main objective of this paper is to provide an effective tuning mechanism for QoS WLAN, complementary to legacy IEEE 802.11 and 802.11e.

1: INTRODUCTION

The primary drawback of IEEE 802.11[1] is the lack of quality-of-service (QoS) functionality that is demanded by real-time and non-real-time application. To overcome this, the IEEE 802.11 association develops a media access control (MAC) layer QoS enhancements to the IEEE 802.11 standard called IEEE 802.11e[2] that includes two access schemes, hybrid coordination function (HCF) provides a contention-free access for centrally coordination and enhance distributed channel access function (EDCAF) provides a contention based access for distributed coordination. Regarding the EDCAF, each station can have 8 user priorities (UP) mapped into 4 access category (AC) at MAC layer. Each AC is assigned to a different type of QoS requirements by the different value of contention parameters, namely the arbitration interframe space number (*AIFSN*), minimum contention window size (CW_{min}), maximum contention window size (CW_{max}), persistence factor (*PF*) and the limit of transmission opportunity (*TXOP_limit*).

AIFSN is the number of time slots for a given AC that has to wait before it starts the backoff procedure. CW_{min} and CW_{max} are used for deciding the value of contention window for backoff procedure, *PF* determines how to increase contention window after collision, and the limit of TXOP (*TXOP_limit*) is the duration of transmitted continuously.

The IEEE 802.11e specification does not provide the optimization values and tuning algorithm of contention parameters and only provide the default suggestion values. So it can not overcome the run-time and variable WLAN environment. Most analytic models [3]-[8] and proposed algorithms [9]-[17] just analyze the influence of contention parameters to the QoS of WLAN, but all do not propose an optimum tuning principle and thought on contention parameters. We focus on tuning *AIFSN* and CW_{min} parameters and optimizing the throughput to meet the requirement of real-time traffic, keep the minimum bandwidth requirement of non-real-time traffic and maintain the services differentiation. The goal of research is to propose a simple optimum scheme (OPT) which can efficiently manage channel bandwidth and service differentiation.

2: ANALYTICAL MODEL of EDCAF

2.1: DESCRIPTION of EDCAF

The contention parameters of EDCAF include the values of *AIFS* and *CW* for each AC, which decide the success probability of channel access of each AC. The difference of success probability of each AC affects the priority of channel access. As shown in Fig. 1, the channel access priority of each AC during specific duration (*Tx_cycle*) is affected by *AIFS* and *CW*. Each *Tx_cycle* contains delay and transmission cycle. A legacy IEEE 802.11e EDCAF performs the CSMA/CA protocol on delay cycle that contains two channel access periods, defer and backoff periods. In the defer period, a station has to sense the channel to determine whether another station is transmitting before initiating a transmission. If the channel is sensed to be free for an *AIFS* interval as Eq. (1), the backoff period may proceed. On the other hand, if the channel is busy, the station must wait another *AIFS* after the channel is idle again. In the backoff period, the station has to wait an additional random backoff time, which is randomly taken from a uniform distribution over the initial interval (0, …, CW_{min}). While the collision occurs, the station selects a new backoff time on an double interval (0, …, $2\times CW_{min}$), twice the length of the initial interval. A collision occurs for the retransmission of the same given packet each time, the station doubles its backoff interval, called binary exponential backoff (BEB), shown as Eq. (2) (*PF*=2) until it reaches the maximum value CW_{max}. The backoff interval length is reset to CW_{min} for any new packet.

After the delay cycle, the station enters the Transmission cycle to decide whether a packet can be successful transmitted or fail based on the channel status. If the channel status is busy, the packet will have a collision, if the channel status is not busy, the station can transmit the packet successfully.

$$AIFS[PM(r, i)] = AIFSN[PM(r, i)] \times T_{Slot} + SIFS \quad (1)$$

$$T_B = random[0, CW] \times T_{Slot} \quad (2)$$

where $CW_{min} \le CW \le CW_{max}$ and

$$CW_{new} = (CW_{old} + 1) \times PF - 1$$

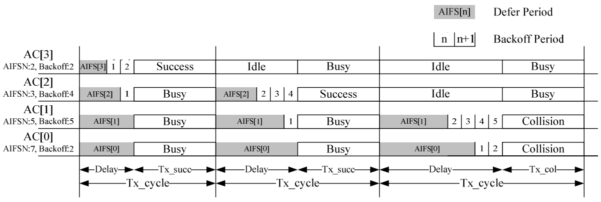

Fig. 1 EDCAF channel status with four access categories

2.2: Formulations

We make the following assumptions about the analytic model. First, we assume ideal channel condition and packet loss due to collision occurrence. Second, we analyze the EDCAF performance when the system operates under saturation conditions, i.e., each AC always has a packet available for transmission.

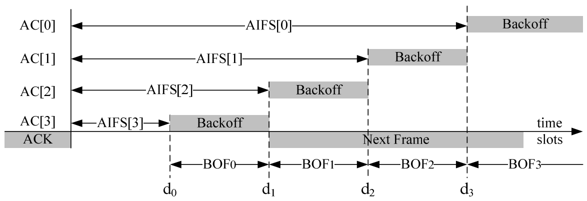

Fig. 2 Analytic Model

From Fig. 2, we divide the possible random backoff period into four BOF_i for i = 0, 1, 2, 3 in the Delay cycle and define the contention parameter set for a corresponding AC[i] as $AIFS[i]$, $CW_{min}[i]$ and $CW_{max}[i]$ for i = 0, 1, 2, 3. For the formulation expressions in the paper, we also define these parameters as four ACs, AC[0], AC[1], AC[2], AC[3], $d_i = AIFSN[3-i] = AIFS[3-i]/T_{Slot}$ and $W_i = CW_{min}[i]+1$ for i=0, 1, 2, 3, d_i is defined as the length of $AIFSN[3-i]$ in slot unit, Wi is the size of contention window minimum and m_i is the maximum numbers of retransmission for AC[i]. From Fig. 2, the priority sequence is AC[3]>AC[2]>AC[1] >AC[0], and $AIFS[3] < AIFS[2] < AIFS[1] < AIFS[0]$. Therefore $d_0 < d_1 < d_2 < d_3$. BOF_i is defined as the period of time between $AIFS[2-i]$ and $AIFS[3-i]$ in slot unit for i=0, 1, 2 thus the length of BOF_i is $BOF_i = d_{i+1} - d_i$ for i=0,1,2, and $BOF_3 = CW_{min}[i] - d_3$ for $CW_{min}[i] \ge d_3$. We define the probability $p_{col,i,j}$ as the collision probability of AC[i] after the d_j. $p_{tr,i,j}$ is the probability as the transmission probability of AC[i] after d_j, note that AC[i] just can transmit packet in the duration of BOF_j based on the condition of $(3-i) \le j$ for i,j=0, 1, 2, 3. i.e., $p_{col,3,1}$ is the collision probability of AC[3] after d_1 and $p_{tr,3,1}$ is the transmission probability of AC[3] after d_1, that contain the duration of BOF_1, BOF_2 and BOF_3.

At saturation mode, a station will always have a queue of packets to send, so every transmission is preceded by a backoff procedure. Since the backoff is uniformly distributed by [0, ⋯, W_i-1] for the first attempt and the average backoff time is $(W_i-1)/2$ in slot unit. We can calculate the average number of backoff slots for a AC[i] after d_{3-i} as geometrically distributed with probability of success $(1-p_{col,i,j})$. A station transmits a packet multiple times until it receives an acknowledgment or reaches the maximum retransmission limit. The average backoff window size $W_{i,j}$ for AC[i] after d_j is shown as Eq. (3), where $(3-i) \le j$ for i,j=0, 1, 2, 3, refer from [7][8].

$$\begin{aligned} W_{i,j} &= (1-p_{col,i,j}) \cdot \frac{W_i - 1 - \sum_{k=0}^{j-1} BOF_k}{2} \\ &+ p_{col,i,j} \cdot (1-p_{col,i,j}) \cdot \frac{2 \cdot W_i - 1 - \sum_{k=0}^{j-1} BOF_k}{2} + \cdots \\ &+ p_{col,i,j}^{m_i} \cdot (1-p_{col,i,j}) \cdot \frac{2^{m_i} \cdot W_i - 1 - \sum_{k=0}^{j-1} BOF_k}{2} \\ &+ p_{col,i,j}^{m_i+1} \cdot \frac{2^{m+1} \cdot W_i - 1 - \sum_{k=0}^{j-1} BOF_k}{2} \\ &= \frac{W_i}{2}\left[\frac{1 - p_{col,i,j} - p_{col,i,j}\left(2p_{col,i,j}\right)^{m_i}}{1-2p_{col,i,j}}\right] - \frac{1}{2} - \frac{1}{2}\sum_{k=0}^{j-1} BOF_k \end{aligned} \quad (3)$$

The average backoff window size $W_{i,j}$ and transmission probability of $p_{tr,i,j}$ can be approximated by

$$\begin{aligned} W_{i,j} &\approx \frac{W_i}{2} - \frac{1}{2} - \frac{1}{2}\sum_{k=0}^{j-1} BOF_k \\ &= \frac{1}{2}\left(W_i - 1 - \sum_{k=0}^{j-1} BOF_k\right) \approx \frac{1}{2}\left(W_i - \sum_{k=0}^{j-1} BOF_k\right) \end{aligned} \quad (4)$$

Since $W_i >> 1$,

$$\begin{aligned} p_{tr,i,j} &= \frac{1}{W_{i,j}} \approx \frac{2}{\left(W_i - \sum_{k=0}^{j-1} BOF_k\right)} \\ &\approx \frac{2}{\left(W_i - \alpha\right)} \approx \frac{2}{W_i} \end{aligned} \quad (5)$$

where $\alpha = \sum_{k=0}^{j-1} BOF_k$ and assume $\alpha << W_i$.

The transmission probability $p_{tr,i,j}$ goes to zero as the number of CW_{min} increases. This is due to the average backoff window size increases as the number of CW_{min} increases. Therefore the different contention window minimum CW_{min} will affect the transmission probability of station, and the lower transmission probability can help to reduce the collision rate.

The average backoff window size $W_{i,j}$ and transmission probability of $p_{tr,i,j}$ can be approximated by

$$W_{i,j} \approx \frac{W_i}{2} p_{col,i,j} \left(2 p_{col.i,j}\right)^{m_i} - \frac{1}{2} - \frac{1}{2} \sum_{k=0}^{j-1} BOF_k$$
$$\approx \frac{W_i}{2} p_{col,i,j} \left(2 p_{col,i,j}\right)^{m_i} \approx 2^{m_i - 1} W_i \tag{6}$$

Since $\frac{W_i}{2} p_{col,i,j} \left(2 p_{col.i,j}\right)^{m_i} >> \frac{1}{2} + \frac{1}{2} \sum_{k=0}^{j-1} BOF_k$

and $p_{col,i,j}^{m_i+1} \approx 1$.

$$p_{tr,i,j} = \frac{1}{W_{i,j}} \approx \frac{1}{2^{m_i - 1} W_i} \tag{7}$$

From Eqs. (6) and (7), the minimum contention window has a major effect on the average backoff window size and the transmission probability, in contrast, the differentiated *AIFS* value has only a small effect on $W_{i,j}$ and $p_{tr,i,j}$. When the CW_{min} value is increased, the average backoff windows size is increased, the probability of two stations to choose the same slot is reduced and the transmission probability is decreased.

Considering the results obtained, in the circumstances of lower collision rate, a higher contention window minimum can reduce the transmission probability of stations and reduce the collision rate. A higher differentiated *AIFS* value can raise the transmission probability of higher priority stations. In the circumstances of higher collision rate, the effect of differentiated *AIFS* is smaller than contention window minimum, and a higher contention window minimum can reduce the transmission probability of stations and improve the collision rate of system and throughput.

3: ANALYSIS of IEEE 802.11e EDCAF

In this section, we investigate the relation of system throughput and contention parameters. In order to evaluate the effect of *AIFSN* and CW_{min}, we develop a simulator by C++ to determine the realized throughput as a function of offered station numbers based on DCF and EDCAF WLANs. Several assumptions were decided to reduce the complexity of the simulation model : the propagation delay were neglected, the channel is no interference and error free, no hidden node issue and we consider the saturation mode on the basic access scheme which means stations always have packets to be transmitted on basic access scheme. The simulation results show the best throughput possible with the given parameters and the number of stations.

3.1: Simulation environment

In the simulation environment, we consider the DCF and the EDCAF networks based on IEEE 802.11b standard with a variable number of stations. Other general simulation parameters are summarized in Table 1. In these simulations, the number of stations range from 2 to 50. The expected results of throughput show on following four distinct scenarios. Sections 3.2 and 3.3 show the effect of different values of DIFS and CW_{min} for legacy IEEE 802.11 DCF respectively.

3.2: Effect of CW_{min} in legacy EDCAF

This simulation consists of two traffic classes, real-time (RT) and non-real-time (NRT). Each traffic class has the same default parameters as Table 1. Table 2 shows the variable simulation parameters for RT and NRT traffics, RT has higher priority than NRT. We investigate the impact of differentiated CW_{min} as shown in Fig. 3. Differentiating the initial contention window minimum (CW_{min}) has both the functions of tuning collisions ratio and providing priorities. In fact, the throughput differentiation increases a little bit on the same competing stations. High priority stations can receive superior service by having smaller CW_{min}. A smaller CW_{min} corresponds to fewer backoff slots being chosen and that increases the transmission probability per transmission.

Table 1 Simulation Parameters-1

Simulation Parameters	
Packet Size	1024 bytes
Phy Header (include preamble)	192 bits
MAC Header (include CRC)	272 bits
a Slot Time	20 us
SIFS	10 us
DIFS	50 us
Persistence Factor	2
Retry Limit	5
Physical Layer Rate	11 Mbps

Table 2 Simulation Parameters-2

Variable Parameters		
The stations ratio $STAs_{RT}$: $STAs_{NRT}$	1 : 1	
The number of stations	2 ~ 50	
$CWmin_{RT}$ / $CWmin_{NRT}$	3/7,3/15,3/31,3/63,3/127	
CWmax	1023	
AIFSN	2	9

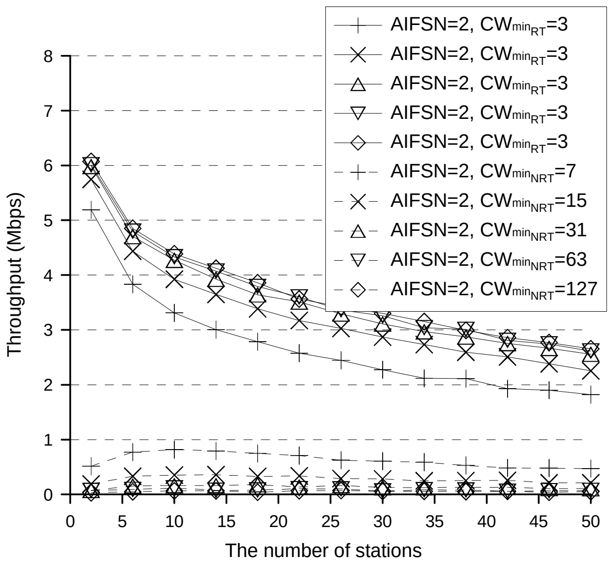

Fig. 3 Throughput versus the number of stations (*AIFSN*=2)

3.3: Effect of *AIFSN* in legacy EDCAF

The simulation investigates the impact of *AIFSN* and presents the result achieved through different *AIFSN* and the number of stations. Table 3 shows the variable simulation parameters used in the simulation and keeps the constant of CW_{min}. We investigate the impact of differentiated *AIFSN* for RT and NRT traffics and show the simulation results. Figure 4 shows a more intensive differentiation in term of throughput with increase of differentiated *AIFSN*. In the larger *AIFSN* differentiation, the NRT traffic may completely lose the opportunity to access medium. The higher priority stations will progress through backoff period relatively faster since they may decrease their backoff counter, while lower priority station still wait for the end of *AIFSN*, and that can lead the lower priority traffic NRT to be starved.

Table 3 Simulation Parameters-3

Variable Parameters		
The stations ratio $STAs_{RT}$: $STAs_{NRT}$	1 : 1	
The number of stations	2 ~ 50	
$AISFN_{RT}$ / $AISFN_{NRT}$	2/3, 2/5, 2/7, 2/9	
CWmax	1023	
CWmin	3	15

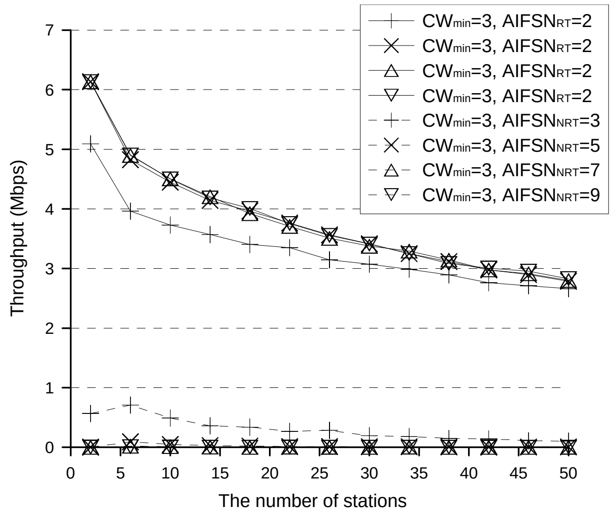

Fig. 4 Throughput versus the number of stations (CW_{min}=3)

4: Performance Evaluation of OPT scheme

The OPT scheme can exist on AP and play a central role of dynamic parameters control. The contention parameters decide QoS level of traffics to service in each AC. Therefore, the contention parameters of EDCAF need to be adjusted by the optimal value to support the required QoS level of traffic in each AC. The tuning scheme of OPT for the contention parameters are achieved by two operations. The first operation is adaptive tuning by the specific duration to find the optimum of contention parameters according to QoS requirements in each AC. The second operation is rescheduling, and stations get the updated contention parameters from AP and contend the channel.

In adaptive tuning operation, OPT adjusts contention parameters value according to the throughput of each AC. Throughput are measured and changed by the competition number of stations during a specific duration. AP can adjust the contention parameters by association information to adjust the transmission opportunity of stations. AP is in charge of measuring the system throughput and judging whether the parameters should be changed or not. In rescheduling operation, AP finds the optimum contention parameters and broadcasts to all stations in beacon frame. After receiving the beacon frame, each station updates its contention parameters to a new value and to contend the channel.

In IEEE 802.11 without QoS environment, the OPT scheme employs measurements of the throughput taken in AP and observes whether the parameters should be modified or not. When AP finds that the present throughput is less than the past measurement, the AP continues to increase CW_{min} and improves the throughput, otherwise OPT will reduce CW_{min} to search the optimal value of CW_{min}. In IEEE 802.11e with QoS environment, OPT first search the optimal ratio of service differentiation by tuning *AIFS* and CW_{min}. AP continues to monitor the ratio of service differentiation and change CW_{min} to give the better differentiated ratio and avoid the bandwidth starvation of low priority.

To implement the OPT scheme by C++, we compare the throughput of OPT with the standard of IEEE 802.11 DCF and IEEE 802.11e EDCAF under the same situation. The simulation uses the default DCF and EDCAF parameters as shown in Tables 4 and 5, respectively, and the other parameters as shown in Table 1. Figure 5 compares the throughput of OPT with the standard DCF. From the result, the throughput of OPT is always higher than that of the DCF and OPT, because OPT can optimize the system throughput according to the number of competing stations. OPT can dynamically tune the CW_{min} to avoid occurrence of higher collision rate and provide higher throughput. Figure 6 compares the service differentiation of OPT and EDCAF. From the result, OPT can provide a stable service differentiation (RT:NRT=2:1) and avoid the bandwidth starvation of low priority NRT, because OPT can dynamically adjust the CW_{min} and *AIFS* to maintain a higher throughput and a specific service differentiation respectively.

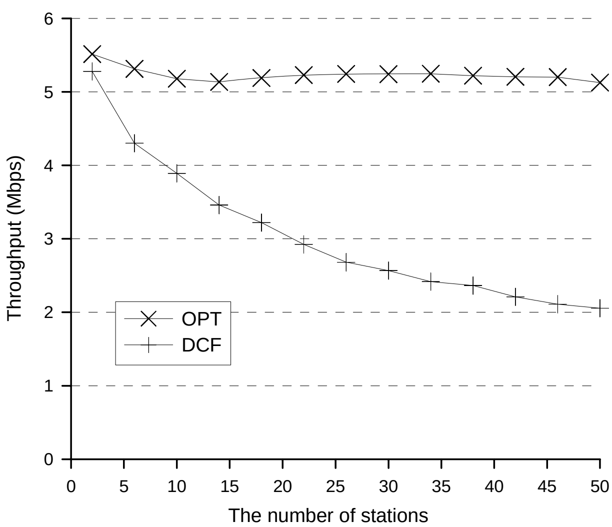

Fig. 5 Throughput versus the number of stations

Table 4 DCF simulation parameters

Simulation Parameters	
The number of stations	2 ~ 50
N (DIFS = SIFS + N*T_{slot})	2
CWmin	3
CWmax	1023

Table 5 EDCAF simulation parameters

Simulation Parameters	
$STAs_{RT}$: $STAs_{NRT}$	1 : 1
Differentiation ratio RT : NRT	2 : 1
The number of stations	2 ~ 50
$AIFSN_{RT}$ / $AIFSN_{NRT}$	2 / 3
$CWmin_{RT}$ / $CWmin_{NRT}$	10 / 13
CWmax	1023

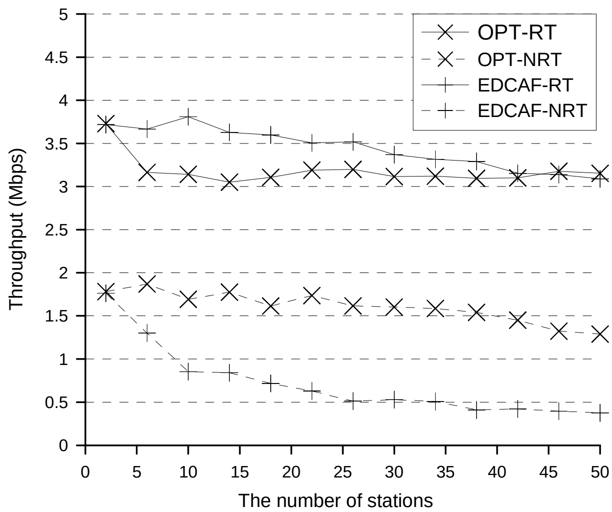

Fig. 6 Throughput versus the number of stations

5: CONCLUSIONS

The performance of IEEE 802.11 DCF and IEEE 802.11e EDCAF can be improved by turning the contention parameters dynamically. In this paper, we overcome the issues, including how to maximize the channel utilization, how to provide the service differentiation and how to avoid the bandwidth starvation. The proposed OPT has the low complexity and is easy to be implemented. The results of simulation show that the OPT scheme gives better performance than the legacy DCF and EDCAF. High priority RT and low priority NRT are well differentiated and NRT is never starved. The simulations also help us to understand and control the behaviors of *AIFS* and CW_{min} parameters in WLAN.

REFERENCES

[1] IEEE Std. 802.11b-1999, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Higher-Speed Physical Layer Extension in the 2. 4 GHz Band".

[2] IEEE 802.11e WG. "Draft supplement to Part 11: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications: MAC Enhancements for Quality of Service (QoS), IEEE Std. 802.11e/D9.0," August 2004.

[3] F. Cali', M. Conti, E. Gregori, "Dynamic Tuning of the IEEE 802.11 Protocol to Achieve a Throughput Limit," IEEE Trans. on Networking, Vol. 8, No. 6, pp. 785-799, Dec. 2000.

[4] J. W. Robinson and T. S. Randhawa, "Saturation throughput analysis of IEEE 802.11e enhanced distributed coordination function," IEEE Journal on Selected Areas in Communications, vol. 22, no. 5, pp. 917-928, 2004.

[5] Z. Kong, D. H. K. Tsang, B. Bensaou, and D. Gao, "Performance analysis of IEEE 802.11e contention-based channel access," IEEE journal on Selected Areas in Communications, vol. 22, no. 10, pp. 2095-2106, 2004.

[6] Hayoung Yoon and JongWon Kim, "Saturation Throughput Analysis of IEEE 802.11e Contention-Based Channel Access," in Proc. of IEEE ISPACS 2005, Hong Kong, Dec. 2005.

[7] J. Hui and M. Devetsikiotis, "A Unfied Model for the Saturation Throughput and Delay Analysis of IEEE 802.11e EDCF," IEEE Transactions on Communications, vol. 53, no. 9, Sep. 2005.

[8] Y. C. Tay and K. C. Chua, "A capacity analysis for the IEEE 802.11 MAC protocol," Wireless Networks, pp. 159-171, Jul. 2001.

[9] A. T. Veres, M. Barry Campbell, and L. H. Sun, "Supporting service differentiation in wireless packet networks using distributed control," IEEE Journal on Selected Areas in Communications, vol. 19, no. 10, pp. 2081-2093. Oct. 2001.

[10] L. Gannoune, and S. Robert, "Dynamic tuning of the contention window minimum (CW_{min}) for enhanced service differentiation in IEEE 802.11 wireless ad-hoc networks," IEEE international symposium on personal, indoor and mobile radio communications (PIMRC 2004), Barcelona, Spain, Sept. 2004.

[11] L. Romdhani, Qiang Ni, and T. Turletti, "Adaptive EDCF: enhanced service differentiation for IEEE 802.11 wireless ad-hoc networks," IEEE Wireless Communications and Networking, vol. 2, pp. 1373-1378, March 2003.

[12] L. Bononi, M. Conti, and E. Gregori, "Runtime Optimization of IEEE 802.11 WLANs Performance," IEEE Transactions on Parallel and Distributed. Systems, vol. 15, no. 1, pp. 66-80, Jan. 2004.

[13] H. Ma, X. Li, H. Li, P. Zhang, S. Luo, C. Yuan, "Dynamic optimization of IEEE 802.11 CSMA/CA based on the number of competing stations," Proc. of IEEE ICC, Paris, France, June 2004.

[14] Chonggang Wang, Weiwen Tang, Kazem Sohraby, and Bo Li, "A simple mechanism on MAC layer to improve the performance of IEEE 802.11 DCF," Proc. of BroadNet 2004, Oct. 2004.

[15] Filali, Fethi, "Dynamic and efficient tuning of IEEE 802.11 for multimedia applications," IEEE international symposium on personal, indoor and mobile radio communications (PIMRC 2004), Barcelona, Spain, Sept. 2004.

[16] Jianhua He, Dritan Kaleshi, Alistair Munro, Michael Barton, "management of services differentiation and guarantee in IEEE 802.11e wireless LANs," Proc. of IEEE VTC Spring, Stockholm, June 2005.

[17] S. El Housseini, and H. Alnuweiri, "Adaptive Contention-Window MAC Algorithms for QoS-Enabled Wireless LANs," IEEE International Conference on Wireless Networks, Communications and Mobile Computing, vol. 1, pp. 368-374, June 2005.

[18] P. Serrano, A. Banchs and J. F. Kukielka, "Detection of Malicious Parameter Configurations in IEEE 802.11e EDCA," IEEE Globecom 2005, St. Louis, Missouri, Nov. 2005.