Integrated quality-of-service differentiation over IEEE 802.11 wireless LANs

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Abstract: The fundamental medium access control mechanism in IEEE 802.11 wireless LANs (WLANs)–distributed coordination function (DCF) only supports the best-effort service and does not support quality-of-service (QoS) differentiation. Enhanced distributed channel access (EDCA) in IEEE 802.11e supports delay differentiation. A new approach, EDCA+, is proposed to enhance QoS over WLANs. It simultaneously achieves bandwidth, delay and jitter differentiation by distinguishing the minimum contention window, the maximum backoff stage or persistent factor and packet-loss rate differentiation by distinguishing the retry limit. Analytical models are proposed to analyse the performance of EDCA+ in terms of throughput, bandwidth, delay, jitter and packet-loss rate. Extensive simulations are also carried out to evaluate the accuracy of the proposed performance models and to compare the performance of DCF, EDCA and EDCA+. The simulation results show that EDCA+ performs better than DCF and EDCA in ensuring integrated QoS, and that the proposed analytical models are valid.

1 Introduction

In recent years, wireless LANs (WLANs) have been widely used as an essential technology in providing broadband wireless access. The performance analysis and improvement of WLANs have attracted much research interest. IEEE 802.11 is a widely adopted WLAN standard. Its fundamental medium access control (MAC) mechanism, distributed coordination function (DCF), only supports the best-effort service and does not support quality-of-service (QoS) differentiation. However, there is an increasing demand that multimedia services with different QoS requirements should be supported by WLANs. Different multimedia services have different QoS requirements with respect to bandwidth, delay, jitter and packet-loss rate. In order for WLANs to support multimedia applications, the MAC protocol must support a degree of QoS differentiation. In DCF, all the traffic classes have the same contention parameters, such as the minimum contention window ($CW_{\text{min}}$), the maximum contention window ($CW_{\text{max}}$), persistent factor ($F$), the maximum backoff stage ($m$) and interframe space (IFS). Hence, all the services have the same priority when accessing the channel. One possible solution is to provide a good priority scheme by differentiating the contention parameters, thereby achieving QoS differentiation [1–17]. The enhanced DCF in IEEE 802.11e, enhanced distributed channel access (EDCA), supports QoS applications [1]. However, all of the above protocols have only considered the QoS requirements on delay. It is highly desirable that WLANs should be able to provide integrated QoS differentiation that includes bandwidth, delay, jitter and packet-loss rate differentiation.

A modified DCF protocol was very briefly presented as a letter in [18]. It shows that delay and packet-loss rate differentiation can be achieved by differentiating $CW_{\text{min}}$ and the retry limit ($m'$), respectively. In this paper, we will elaborate on the modified EDCA protocol called EDCA+ in much greater detail, and revise and substantially extend the preliminary results presented in the letter. The modified DCF in the letter [18] can only provide delay and packet-loss rate differentiation. However, this paper shows that EDCA+ can provide bandwidth, delay and jitter differentiation by distinguishing $CW_{\text{min}}$, $m$ or $F$, and can also provide packet loss guarantees by distinguishing $m'$. As bandwidth, delay and jitter are highly interdependent, they are discussed collectively. Another important contribution of this paper is to postulate a simple and accurate analytical model, which takes into account the details of EDCA+. The results can be used to calculate the saturation throughput, bandwidth, delay, jitter and packet-loss rate for each traffic class. In addition, extensive performance simulations of the DCF, EDCA and EDCA+ protocols are undertaken. Simulation results show that EDCA+ supports integrated QoS differentiation, whereas DCF does not support any QoS differentiation and EDCA supports bandwidth, delay and jitter differentiation. This result is very fortunate for EDCA as the protocol was initially designed only for delay differentiation.

The rest of this paper is organised as follows. In Section 2, DCF, EDCA and EDCA+ are introduced, respectively. In Section 3, analytical models are proposed to theoretically analyse the performance of EDCA+. In Section 4, simulation studies are carried out to evaluate the proposed models and to compare the performances of DCF, EDCA and EDCA+. Section 5 deals with concluding remarks and recommends future research.
2 Description of DCF, EDCA and EDCA+

In DCF, if a station has a new packet to transmit, it will monitor the channel activities first. If the channel has been idle for a period of time, that is a distributed IFS (DIFS), the station will transmit. Otherwise, if the channel is sensed busy, the station will continuously monitor the channel until it is found to be idle for a DIFS. At this point, the station generates a random backoff interval before transmitting. The backoff time is slotted, and the slot size is called aSlotTime. At each packet transmission, the backoff time is uniformly distributed in [0, CW-1]. At the first transmission attempt, CW = CWmin. After each unsuccessful transmission, CW will be doubled, until it reaches its maximum value CWmax = F^CWmin, where F = 2. Once CW reaches CWmax, it will remain at this value until the packet is transmitted successfully or the retransmission time reaches m'. When the retry limit is reached, retransmission attempts will cease and the packet will be discarded.

EDCA, originally called EDCF, is the main part of the IEEE 802.11e standard for service differentiation. EDCA introduces a concept of access categories (ACs). Different ACs adopt different values of arbitrary IFS (AIFS), CWmin, m and transmission opportunity (TXOP) for acquiring channel access. For example, before transmitting, each node needs to wait for a period of time called AIFS for the channel to be idle. The value of AIFS is associated with the corresponding traffic flow. TXOP is the time interval permitted for a particular node to transmit packets. During the TXOP, there can be a series of frames transmitted by the node. Typically, a shorter AIFS and a longer TXOP are associated with a traffic flow with a higher priority. To introduce better differentiation performance, EDCA extends the basic DCF to support up to four EDCA queues in one QoS-enhanced station. Each of these queues competes to send the packets. However, this paper will not consider the internal collision, which may result from this queuing.

Generally, important QoS metrics includes bounds on bandwidth, delay, jitter and packet-loss rate. Real-time applications have strict delay requirements, but are not very sensitive to packet loss. For example, a loss rate of 1–3% is acceptable in most cases. Best-effort applications are sensitive to packet loss, but can tolerate large delays. In [1–17], both real-time and best-effort traffics have the same packet-loss rate. If the packet-loss-rate bound is set according to the requirements of real-time traffic, the QoS of best-effort traffic cannot be guaranteed. If the packet-loss-rate bound is set according to the requirement of best-effort traffic, real-time traffic will get a higher than required packet loss assurance. This will result in the reduction of available bandwidth that can be allocated to other traffic requests. Therefore an integrated QoS differentiation approach, which can specify different QoS requirements on bandwidth, delay, jitter and packet-loss rate for different services, is needed. Note that this paper is focused on MAC protocols, and the use of higher-level protocols to guarantee QoS is out of the scope of this paper.

In EDCA+, to achieve the integrated QoS differentiation, different services are assigned different contention parameters, such as CWmin, F, m, CWmax, AIFS, TXOP and m'. The first six parameters are the major factors, which affect bandwidth, delay and jitter. Actually, CWmax is inter-related to CWmin, F and m according to its definition in DCF. However, for simplicity, only CWmin, F and m are considered in this paper. The retransmission limit, m', is a major factor that affects packet-loss rate. Therefore EDCA+ will provide integrated QoS differentiation (in terms of bandwidth, delay, jitter and packet-loss rate) by tuning CWmin, F, m and m'.

With EDCA+, service requests are first graded into M grades according to QoS requirements of bandwidth, delay and jitter. The relationship between contention parameters and grades are given as

\[
\begin{align*}
W_{i,0} &\leq W_{j,0} \\
F_i &\leq F_j \\
m_i &\leq m_j
\end{align*}
\]

(1)

where \(W_{i,0}, W_{j,0}, F_i, F_j, m_i \) and \(m_j \) are CWmin, F and m of the \(i\)th and the \(j\)th class traffic, respectively. The simulation results in Section 4 show that bandwidth, delay and jitter are closely related. Thus, they are analysed together.

Secondly, service requests are graded into N grades according to QoS requirement of packet-loss rate. The relationship between contention parameters and grades is given as

\[
m_i' \leq m_j' \quad 0 \leq i < j \leq N - 1
\]

(2)

where \(m_i' \) and \(m_j' \) are the \(i\)th and the \(j\)th grades of \(m'\), respectively.

As bandwidth, delay, jitter differentiation and packet-loss rate differentiation are independent, the total number of traffic classes can approach \(C = M \times N\).

3 Performance analysis

One of the key contributions of this paper is the analytical evaluation of the saturated throughput, bandwidth, delay, jitter and packet-loss rate of each traffic class. Under the assumption of ideal channel conditions with no hidden terminals and capture, the works in [10, 18–21] analysed saturation throughput and delay in DCF and EDCF, respectively. In saturation conditions, each station has a packet available for transmission immediately after the completion of each successful transmission. Based on them, an analytical model for EDCA+ is proposed in this paper, and two improvements have been made. Firstly, an analytical model that differentiates four contention parameters, CWmin, m, F and m' is derived. Secondly, a simple and accurate method is proposed to calculate saturation throughput, bandwidth, delay, jitter and packet-loss rate of each traffic class. The advantage of the proposed model is that not only it is simple and accurate but also it can provide a theoretical analysis for integrated QoS differentiation.

3.1 Markov chain model

Assume there are \(C\) traffic classes with distinct QoS requirements, and each station belongs to only one priority class, that is, as stated internal collision is not being considered.

Consider a fixed number \(n\) of contending stations, and \(n = \sum_{i=0}^{C-1} n_i\), where \(n_i (0 \leq i \leq C - 1)\) is the number of stations that generate packets of the \(i\)th class traffic.

Let us consider the contention procedure of a station with the \(i\)th class traffic. Let \(s(t, i)\) be the stochastic process representing the backoff stage of the \(i\)th class traffic at time \(t\); \(s(i, t) \in [0, m_i]\). Let \(b(i, t)\) be the stochastic process representing the backoff time counter of the \(i\)th class traffic at time \(t\); \(b(i, t) \in [0, W_{i,j}-1]\), where

\[
W_{i,j} = \begin{cases} 
(F_j/W_{i,0}) & 0 \leq j \leq m_i \\
(F_j/m_i W_{i,0}) & m_i < j \leq m_i'
\end{cases}
\]

(3)
Based on [19], a three-dimensional Markov chain \( \{i, s(i, t), b(i, t)\} \) is shown in Fig. 1.

Let the stationary distribution of the chain be

\[
b_{i,j,k} = \lim_{t \to \infty} P\{i, s(i, t) = j, b(i, t) = k\} \quad 0 \leq j \leq m_i^j,\]

\[
0 \leq k \leq W_{ij} - 1
\]

By analysing the chain, the following equations can be obtained

\[
b_{i,j-1,0} \cdot p_i = b_{i,j,0} = (p_i)^j b_{i,0,0} \quad 1 \leq j \leq m_i^j
\]

\[
b_{i,j,k} = \frac{W_{ij} - k}{W_{ij}} b_{i,j,0} \quad 0 \leq j \leq m_i^j, \quad 0 \leq k \leq W_{ij} - 1 \quad (6)
\]

where \( p_i \), the probability that a transmitted packet collides, is assumed to be independent of the backoff procedure.

Hence, all the values of \( b_{i,j,k} \) can be expressed as functions of \( b_{i,0,0} \) and the conditional collision probability \( p_i \). By substituting the above two equations into the normalisation condition \( \sum_{j=0}^{m_i^j} \sum_{k=0}^{W_{ij}-1} b_{i,j,k} = 1 \), the following equation is obtained

\[
b_{i,0,0} = \begin{cases} 
\frac{2(1-F_i p_i)(1-p_i)}{W_{ij}(1-(F_i p_i)^m_i^j)(1-p_i)} & m_i^j \leq m_i \\
\frac{2(1-F_i p_i)(1-p_i)}{W_{ij}(1-(F_i p_i)^m_i^j)(1-p_i)} + (1-F_i p_i)(1-(p_i)^m_i^j+1) & m_i^j > m_i 
\end{cases}
\]

The probability that the station transmits packets of the \( i \)th class in a randomly chosen time slot is

\[
\tau_i = \frac{1-(p_i)^{m_i^j+1}}{1-p_i} b_{i,0,0}
\]

The probability of collision is

\[
P_c = 1 - (1 - \tau_i)^{m_i^j+1} \prod_{j=0}^{C-1} (1 - \tau_{ij})^{C_s}
\]

By solving the above two equations, the values of \( p_i \) and \( \tau_i \) can be found.

Now, the probability that at least one station with packets of the \( i \)th class transmits in a given time slot can be derived as follows

\[
P_{\tau,i} = 1 - (1 - \tau_i)^{m_i^j}
\]

The probability that exactly one station will transmit packets of the \( i \)th class on the channel, assuming that at least one station will transmit, can be expressed as

\[
P_{\tau,i} = \frac{n_i \tau_i (1 - \tau_i)^{m_i^j} \prod_{j=0}^{C_i-1} (1 - \tau_{ij})^{C_s}}{P_{\tau,i}}
\]

\[
= \frac{n_i \tau_i (1 - \tau_i)^{m_i^j} \prod_{j=0}^{C_i-1} (1 - \tau_{ij})^{C_s}}{1 - (1 - \tau_i)^{m_i^j}}
\]

With regard to the status of packet transmission in a given time slot, there are three possibilities. First, there may be no transmission with a probability of \( P_e = \prod_{i=0}^{C-1} (1 - \tau_i)^{m_i^j} \), whose time is \( \sigma = \text{SlotTime} \). Secondly, it contains a successful transmission. The probability that the station with the \( i \)th class packets transmits successfully is \( P_{\tau,i} b_{i,0,0} \), with an average time \( T_{i} \). Finally, there may be collision with a probability of \( P_c = 1 - P_e - \sum_{i=0}^{C-1} P_{\tau,i} b_{i,0,0} \), whose average time is \( T_c \). \( T_{i} \) and \( T_c \) are discussed in detail in [19]. So the average length of slot is obtained

\[
\hat{S} = P_e \sigma + \sum_{i=0}^{C-1} P_{\tau,i} b_{i,0,0} T_{i} + P_c T_c
\]

Let the average time length of packet payload of the \( i \)th class traffic be \( T_e \). Thus, the normalised saturation throughput \( \eta \) can be expressed as

\[
\eta = \frac{\text{Average payload successfully transmitted in a slot}}{\text{Average length of a slot}}
\]

\[
= \frac{\sum_{i=0}^{C-1} P_{\tau,i} b_{i,0,0} T_{i}}{P_e \sigma + \sum_{i=0}^{C-1} P_{\tau,i} b_{i,0,0} T_{i} + P_c T_c}
\]

### 3.2 Saturation bandwidth, delay, jitter and packet-loss rate

Let the average bit size of packet payload of the \( i \)th class traffic be \( E_i \). Then the bandwidth used by the \( i \)th class traffic is

\[
B_i = \frac{P_{\tau,i} b_{i,0,0} E_i}{P_e \sigma + \sum_{i=0}^{C-1} P_{\tau,i} b_{i,0,0} T_{i} + P_c T_c}
\]

According to Fig. 1, the probability that a station successfully transmits a packet of the \( i \)th class at the \( k \)th backoff stage is

\[
P_{i,j} = (1-p_i) p_i^j \quad 0 \leq j \leq m_i^j
\]

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**Fig. 1** Three-dimensional Markov chain model for class \( i \) traffic

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And its average delay is

\[ T_{ij} = \text{DIFS} + \frac{\alpha}{2} \cdot \sum_{j=0}^{m'_{i}} (W_{ij} - 1) + j \cdot T_c \quad 0 \leq j \leq m'_{i} \] (16)

In fact, during the backoff process, other stations may be allowed to transmit their frames. That is to say, the backoff process may be interrupted. Hence, the above equation should be changed to

\[ T_{ij} = \text{DIFS} + \frac{\alpha}{2} \cdot \sum_{j=0}^{m'_{i}} (W_{ij} - 1) + j \cdot T_c \quad 0 \leq j \leq m'_{i} \] (17)

Hence, the packet delay of the \( i \)th class traffic is

\[ D_i = \sum_{j=0}^{m'_{i}} P_{ij} T_{ij} \] (18)

As shown in Fig. 1, the current (not average) delay that a packet of the \( i \)th class is transmitted successfully at the \( j \)th backoff stage is

\[ X_{i,j,k} = \text{DIFS} + k \cdot \tilde{S} + j \cdot T_c \quad 0 \leq k \leq K_{i,j} \] (19)

where \( k \) is the sum of backoff slots that the packet encounters, and \( K_{i,j} = \sum_{0}^{w(W_{ij} - 1)} \).

Let the probability that a packet of the \( i \)th class is transmitted successfully at the \( j \)th backoff stage and encounters \( k \) backoff slots that are \( P_{i,j,k} \). The jitter of frames for the \( i \)th class can be expressed as

\[ J_i = E\left( |X_{i,j,k} - E(X_{i,j,k})| \right) = \sum_{j=0}^{m_{i}} P_{i,j} \cdot |X_{i,j} - D_i| \] (20)

However, because of the complexity in calculating the probability \( P_{i,j,k} \), an approximation of \( J_i \) is given in this paper

\[ J_i = E\left( |T_{ij} - E(T_{ij})| \right) = \sum_{j=1}^{m'_{i}} P_{ij} \cdot |T_{ij} - D_i| \] (21)

It is intuitive that the approximation in the above equation will become more accurate as \( \text{CW} \), \( m' \), and \( n \) increase in size.

The packet-loss rate for the \( i \)th class traffic is

\[ P_{i,d} = (p_i)^{m'_{i}+1} \] (22)

The packet-loss rate is dependent on its QoS class. As \( 0 < p_i < 1 \), the larger \( m'_{i} \), the smaller the packet loss rate is.

### 4 Simulation results

To evaluate the performance of EDCA+ and the accuracy of the proposed analytical models, extensive simulations are carried out. The values of the parameters used to obtain numerical results for both the analytical models and simulations are specified in IEEE 802.11b. The channel data rate is fixed at 11 Mb/s. For simplicity, the channel is assumed to be ideal without hidden terminals and capture. Let us assume that the number of stations increases from 10 to 30 in a step of two stations each time, and that each station always has packets to be transmitted.

As the proposed QoS differentiation scheme in EDCA+ is generic, many levels of traffic classes can be designated. Yet for simplicity, it is assumed that each station belongs to one traffic class, and traffic is classified into two priority classes with equal number of stations. The packet payload sizes for both traffic classes are fixed at 1023 bytes. The contention parameters are set as follows: in DCF, \((\text{CW}_{\text{min}}, m, F, m') = (32, 5, 2, 7)\) for both classes; in EDCA, \((24, 4, 1.5, 7)\) for class 1 and \((32, 5, 2, 7)\) for class 2; in EDCA+, \((24, 4, 1.5, 6)\) and \((32, 5, 2, 8)\) for the two classes, respectively.

The performance comparisons of DCF, EDCA and EDCA+ are shown in Figs. 2–6, which demonstrate that simulation results are close to the analytical results. This implies that the proposed analytical models are valid. Fig. 2 shows that the saturation throughput decreases slowly with the number of nodes as the collisions increase. In EDCA and EDCA+, the class-1 traffic has a smaller \( \text{CW} \), which causes more collisions. The more the collisions, the more sharply the throughput decreases. So the throughputs of EDCA and EDCA+ are slightly lower than that of DCF.

Fig. 3 shows that in DCF, the bandwidth used by the class-1 traffic is equal to that of the class-2 traffic, and that in both EDCA and EDCA+ the bandwidth used by the class-1 traffic is much higher than that of the class-2 traffic. That is to say, by decreasing \( \text{CW}_{\text{min}}, m \) and \( F \), the class-1 traffic has a higher priority when accessing the channel, so it can borrow part of the class-2 traffic.
bandwidth. Moreover, the difference between EDCA and EDCA+ can be neglected as it is insignificant.

The simulation results demonstrate that the parameters of \(CW_{\min}, m\) and \(F\) have a large effect on bandwidth differentiation, whereas \(m'\) has little effect. Fig. 4 shows that all classes in DCF have the same delay, which implies that DCF does not support delay differentiation. In EDCA and EDCA+, the class-1 traffic has a much lower delay than the class-2 traffic, which implies that both EDCA and EDCA+ support delay differentiation. Moreover, the delay difference between traffic classes in EDCA+ is a marginally larger than that in EDCA; this is caused by the effect of \(m'\).

Fig. 5 shows that all traffic classes in DCF have the same jitter, which implies that DCF does not support jitter differentiation. In EDCA and EDCA+, the class-1 traffic has a much lower jitter than the class-2 traffic, which implies that EDCA and EDCA+ support jitter differentiation. Moreover, the jitter difference between traffic classes in EDCA+ is more pronounced than that in EDCA. This is caused by the effect of \(m'\) again.

In EDCA, the class-1 traffic has a smaller \(CW_{\min}, m\) and \(F\), so it has a higher priority in accessing the channel and can transmit its packets before the class-2 traffic. As more bandwidth is allocated to the class-1 traffic, its delay and jitter also decrease. Hence, bandwidth, delay and jitter differentiation are closely related. This explains why EDCA was proposed to support delay differentiation, but the simulations show that it can simultaneously achieve bandwidth and jitter differentiation.

Fig. 6 shows that all traffic classes in DCF and EDCA have the same packet-loss rate, which implies that neither DCF nor EDCA supports packet-loss rate differentiation. In EDCA+, packet-loss rate of the class-1 traffic is higher than that of the class-2 traffic. It implies that EDCA+ supports packet-loss rate differentiation. Moreover, as there is more collisions in EDCA when compared with DCF the packet-loss rate in EDCA is larger than that in DCF.

In saturation conditions, after the completion of each successful transmission, each station immediately has a packet available for transmission. In fact, the load of the stations is not fixed. Some stations may have data to send during that time, and some others may not. To simulate the performance of EDCA+ in the real environments, the following simulations in unsaturated conditions are carried out. Suppose there are 30 stations and each node generates new packets under a Poisson process. The packet arrival rate is initially set lower than the saturation case, and then subsequently increased so that, at the end of the simulation time, all stations are in a saturation condition.

When the load is light, Figs. 7–10 show that the performance of DCF, EDCA and EDCA+ is similar. When the load is heavy, they have distinct performances in ensuring QoS. Fig. 7 shows that both EDCA and EDCA+ can provide similar bandwidth differentiation, but DCF cannot. Figs. 8...
and 9 show that $CW_{\text{min}}$, $m$, $F$ and $m'$ affect delay and jitter differentiation, and that the first three parameters are considered more important. Fig. 10 shows that $m'$ affects packet-loss rate differentiation, and that $CW_{\text{min}}$, $m$ and $F$ almost do not. Moreover, delay, jitter and packet-loss rate in DCF increase more sharply than those of the class-2 traffic in both EDCA and EDCA+ when the network load increases from 0.5 to 0.6, and their saturated values in DCF are lower than those in EDCA and EDCA+. The crossovers are seen in Figs. 8–10.

5 Conclusions

It is shown in this paper that DCF does not support any kind of QoS differentiation, and EDCA only supports bandwidth, delay and jitter differentiation. EDCA+ supports integrated QoS differentiation, that is to say, bandwidth, delay, jitter and packet-loss rate differentiation, by distinguishing the $CW_{\text{min}}$, $m$, $F$ and $m'$. The real-time traffic with a smaller value of $CW_{\text{min}}$, $m$ and $F$ has a higher priority to access the channel, so it can use a larger bandwidth and has a smaller delay and jitter. On the other hand, the real-time traffic with a smaller value of $m'$ has a larger packet-loss rate than the non-real-time traffic. Simulation results show that EDCA+ is better than both DCF and EDCA in ensuring integrated QoS differentiation under both saturation conditions (as shown in Figs. 3–6) and unsaturation conditions (as shown in Figs. 7–10). The simulation results also demonstrate that the parameters of $CW_{\text{min}}$, $m$ and $F$ have a large effect on bandwidth, delay and jitter differentiation, whereas $m'$ has a large effect on packet-loss rate differentiation. Furthermore, a simple and accurate analytical model is presented to compute the saturation throughput, bandwidth, delay and jitter and packet-loss rate. This approach is one of the first attempts to analyse integrated QoS differentiation.

Through this investigation, four further research topics have been identified. First, in this paper, although EDCA+ provides different traffic classes with integrated QoS differentiation, any combinations of these contention parameters are allowed. To introduce a good differentiation, an optimised combination of contention parameters should be investigated. Therefore in future research, we will extend EDCA+ so that it can provide integrated QoS differentiation using optimised parameter sets to the multimedia services, such as voice, video and data. Second, we shall carry out research on performance analysis of EDCA+ under unsaturated cases. Third, recent research shows that because of selfish behaviours of users, the system performance would by significantly degraded. Selfish users are ready to harm other honest users only if they can derive benefits from this misbehaviour. We shall use a game-theoretic model to interpret and solve the problem of selfish QoS. Finally, as DCF has been used widely, for now and in the near future, EDCA+ will have to work with DCF and/or EDCA in one WLAN cell. In this case, some stations contend for channel in the DCF mode. The whole performance may be degraded. We shall carry out research on hybrid protocols that support DCF, EDCA and EDCA+ simultaneously in a same WLAN cell.

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