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MAC LEVEL BASED QUALITY OF SERVICE MANAGEMENT IN IEEE 802.11 NETWORKS

BY

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Abstract. In order to analyse the capabilities of the IEEE 802.11 MAC (Medium Access Control) sublayer to provide quality of service (QoS) to the users of a wireless local area network (WLAN), the metrics used were throughput, retransmission attempts, medium access delay, and data dropped. Two scenarios using the same physical and MAC parameters, one implementing the distributed coordination function (DCF) and the other, the enhanced DCF (EDCF), were developed in the network simulation tool (OPNET Modeler) to obtain the simulation results. During the evaluation of EDCF, our focus was on the performances of the various access categories. The obtained results show that the performance of EDCF is better in providing QoS for real-time services (voice over IP, video conferencing) as compared to DCF, because of its ability to differentiate and prioritize various network services.

Key words: WLAN; QoS; MAC; DCF; EDCF; real-time services.

1. Introduction

The original 802.11 WLAN MAC sub-layer employs a *distributed coordination function* (DCF) based on the carrier sense multiple access with

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collision avoidance (CSMA/CA) method for medium access, and it is best known for its asynchronous best effort (BE) data transfer. In order to support QoS in 802.11 WLAN, IEEE 802.11e adds a new function called the *hybrid coordination function* (HCF) that includes both the controlled contention-free and the contention-based channel access methods in a single channel access protocol. The HCF uses a contention-based channel access method called *enhanced DCF* (*EDCF*) that operates together with a controlled channel access mechanism based on a central polling mechanism. HCF supports both prioritized and parameterized medium access.

2. MAC Sublayer Protocols

Distributed Coordination Function (DCF) is the currently wide used access protocol. An optional Point Coordination Function (PCF) protocol exists for infrastructure WLANs only. DCF is the basis for the Enhanced Distributed Coordination Function (EDCF) which provides QoS.

2.1. The Distributed Coordination Function (DCF)

DCF is the basic and mandatory MAC mechanism of legacy IEEE 802.11 WLAN. It is based on carrier sense multiple access with collision avoidance (CSMA/CA) protocol. CSMA/CA attempts to avoid collisions by using explicit packet acknowledgment (ACK). The 802.11 standard uses a CA mechanism together with a positive ACK. The MAC sublayer of a station wishing to transmit senses the medium. If the medium is free for a specified time, called the *Distributed Inter-Frame Space* (DIFS), then the station is able to transmit the packet; if the medium is busy (or becomes busy during the DIFS interval), the station defers using the binary exponential backoff algorithm.

The backoff algorithm commonly uses a scheme to solve contention problems among different stations wishing to transmit data at the same time. When a station goes into the backoff state, it waits an additional, randomly a selected number of time slots (in 802.11b a slot has a 20 μs duration and the random number must be greater than 0 and smaller than a maximum value referred to as the *Contention Window* (*CW*)). During this waiting time, the station continues sensing the medium to check whether it remains free or another transmission begins. At the end of its contention window, if the medium is still free, the station can send its frame. If during the contention window another station begins to transmit data, the backoff counter is frozen and counting down starts again when the channel returns to the idle state.

There is a problem related to the CW dimension. With a small CW, if many stations attempt to transmit data at the same time it is very possible that some of them may have the same backoff interval. This means that there will continuously be collisions, with serious effects on the network performance. With a large CW, if few stations wish to transmit data they will likely have long backoff delays, resulting in the degradation of the network performance. The solution is to use a binary exponential grow for CW size. It starts from a small value

$$CW_{\min} = 2^k - 1, \quad (1)$$

where k is a constant (*i.e.*, $CW_{\min} = 31$); then it doubles after each collision

$$CW[i] = 2^{k+i} - 1; \quad (2)$$

i is the number of attempts to transmit data, until it reaches the maximum value $CW_{\max}$ (*i.e.*, $CW_{\max} = 1{,}023$).

In 802.11, the backoff algorithm must be executed in three cases: when the station senses the medium is busy before the first transmission of a packet, after each retransmission or after a successful transmission. This is necessary to avoid a single host wanting to transmit a large quantity of data, occupying the channel for a too long period, and denying access to all other stations. The backoff mechanism is not used when the station decides to transmit a new packet after an idle period and the medium has been free for more than the DIFS (see Fig. 1).

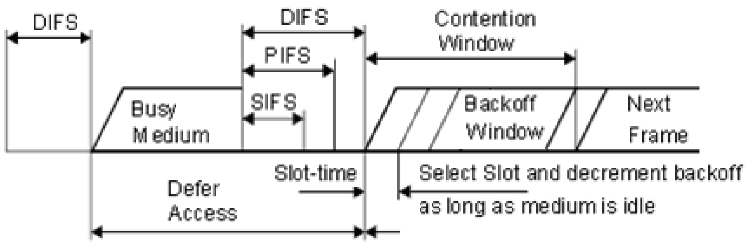

Fig. 1 – CSMA/CA in IEEE 802.11b.

The loss of performance strongly depends on the packet size and data rate, but a 30% loss is more than likely to occur. The smaller the packets, the larger will be the impact of CSMA/CA on network performance. To evaluate the performance impact of CSMA/CA it is important to know how the various inter-frame spaces are defined. The 802.11 standard defines the following four inter-frame spaces to provide different priorities:

a) *Short Inter-Frame Space* (SIFS): it is used to separate transmissions belonging to a single dialog (*e.g.*, fragment-ACK), and represents the minimum inter-frame space. This value is fixed per PHY and is calculated in such a way that the transmitting station will be able to switch back to receive mode and be capable of decoding the incoming packet. For the 802.11 DSSS PHY the value is of 10 μs.

b) *Point Coordinate Inter-Frame Space* (PIFS): it is used by the AP to gain access to the medium before any other station. This value is SIFS plus one slot time (*i.e.*, 30 µs).

c) *Distributed Inter-Frame Space* (DIFS): it represents the inter-frame space used for a station willing to start a new transmission. It is calculated as PIFS plus one slot time (*i.e.*, 50 µs).

d) *Extended Inter-Frame Space* (EIFS): it is the longest inter-frame space used by a station that has received a packet which it could not understand. This is required to prevent the station (which could not understand the duration information for the virtual carrier sense) from colliding with a future packet belonging to the current dialog.

2.2. Enhanced Distributed Coordination Function (EDCF)

EDCF is designed to provide prioritized QoS by enhancing the contention-based DCF. It provides differentiated, distributed access to the wireless medium for QoS access points (QAPs) and QoS stations (QSTAs) using eight different user priorities (UPs). Before entering the MAC sublayer, each data packet received from the higher layer is assigned a specific user priority value. The EDCF mechanism defines four different first-in first-out (FIFO) queues, called *access categories* (ACs) that provide support for the delivery of traffic with UPs to/at the QSTAs. As shown in Fig. 2, each data packet received from the higher layer along with a specific user priority value should be mapped into a corresponding AC according to Table 1.

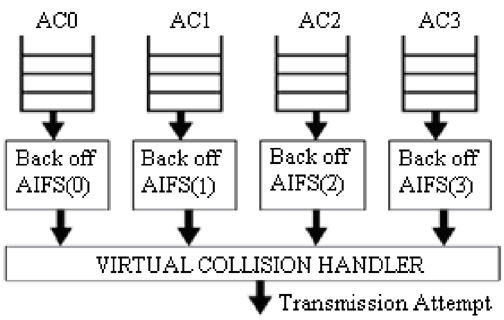

Fig. 2 – Implementation model with four transmission queues.

Table 1
Details of the Access Categories

<table>
<tr><th>AC</th><th>Priority</th><th>Designation</th></tr>
<tr><td rowspan="2">0</td><td>1</td><td>Background</td></tr>
<tr><td>2</td><td>Standard</td></tr>
<tr><td rowspan="2">1</td><td>0</td><td>Best effort</td></tr>
<tr><td>3</td><td>Excellent effort</td></tr>
<tr><td rowspan="2">2</td><td>4</td><td>Streaming multimedia</td></tr>
<tr><td>5</td><td>Interactive multimedia</td></tr>
<tr><td rowspan="2">3</td><td>6</td><td>Interactive voice</td></tr>
<tr><td>7</td><td>Reserved</td></tr>
</table>

Note that the relative priority of 0 is placed between 2 and 3. This relative prioritization is rooted from IEEE 802.1d bridge specification. Different kinds of applications (*e.g.* best effort traffic, video traffic, and voice traffic) can be directed into different ACs. For each AC an enhanced variant of the DCF, called an *Enhanced Distributed Channel Access Function* (*EDCAF*), contends for transmission opportunities (TXOPs).

Each AC behaves like a virtual station: it contends for access to the medium and independently starts its backoff after sensing the medium idle for at least AIFS period. In EDCF a new type of IFS is introduced, the arbitrary IFS (AIFS), in place of DIFS in DCF (see Fig. 3). Each AIFS is an IFS interval with arbitrary length as follows:

$$\text{AIFS [AC]} = \text{SIFS} + \text{AIFSN [AC]} \times \text{slot time}. \tag{3}$$

AIFSN [AC] is called the *arbitration IFS number* and determined by the AC and the physical settings, and the slot time is the duration of a time slot (see Fig. 3). The AC with the smallest AIFS has the highest priority. The values of AIFS [AC], CW min[AC], and CW max[AC], which are referred to as the EDCF parameters, are announced by the AP *via* beacon frames.

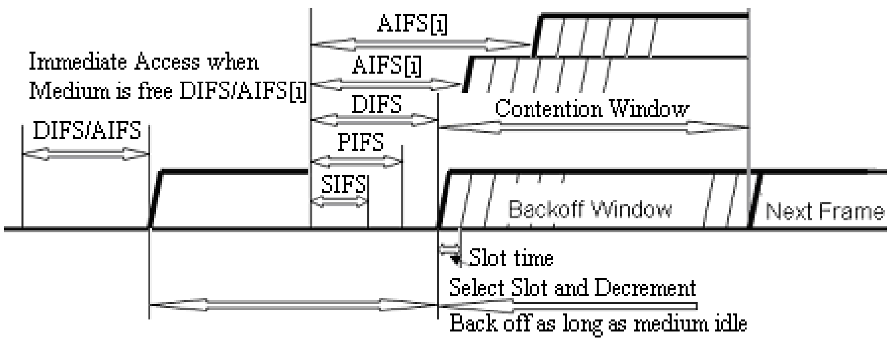

Fig. 3 – The timing relationship for EDCF.

The purpose of using different contention parameters for different queues is to give a low-priority class, *i.e.* a longer waiting time than a high-priority class, so the high-priority class is likely to access the medium earlier than the low-priority class. An internal collision occurs when more than one AC finishes the backoff at the same time. In such a case, a virtual collision handler in every QSTA allows only the highest-priority AC to transmit frames, and the others perform a backoff with increased CW values.

3. Simulation and Obtained Results

3.1. Simulation Scenario for EDCF

In this section we use the network simulator OPNET Modeler to evaluate the performance of IEEE 802.11e EDCA mechanism. The network model consists of two wireless QSTAs with no mobility and a fixed QAP (an infrastructure WLAN) connected to an Ethernet server which is the destination of all applications. We choose 802.11b for the PHY layer, and the data rate is set to 11 Mb/s. The simulation parameters are shown in Table 2.

In case of EDCF, all four traffic classes were fed into the MAC sublayer from higher layer, which are corresponding to AC0, AC1, AC2, and

AC3, respectively to check how efficient is this protocol in providing service differentiation required for real-time applications. Note that DCF does not support service differentiation and ACs. With that end in view in the application definition of EDCF scenario, four applications were configured, one for each access category. Details are shown in the Table 3.

Table 2
The Simulation Parameters

AC	CW_{min} [AC]	CW_{max} [AC]
0	31	1,023
1	31	1,023
2	$(CW_{min}+1)/2–1=15$	$CW_{min} = 31$
3	$(CW_{min}+1)/4–1=7$	$(CW_{min}+1)/2–1=15$

Table 3
Access Category Corresponding to an Application

AC	Application	Designation
0	HTTP	Background
1	Remote login	Excellent effort
2	Video conferencing	Interactive multimedia
3	Voice	Interactive voice

For comparison reasons it was assumed that each AC has 25% of the total data traffic, the same packet rate and the same packet size. In the profile definition, a common profile for all stations was configured to use all the four applications simultaneously. The simulation time was set to 60 s and the results were generated using the time average function.

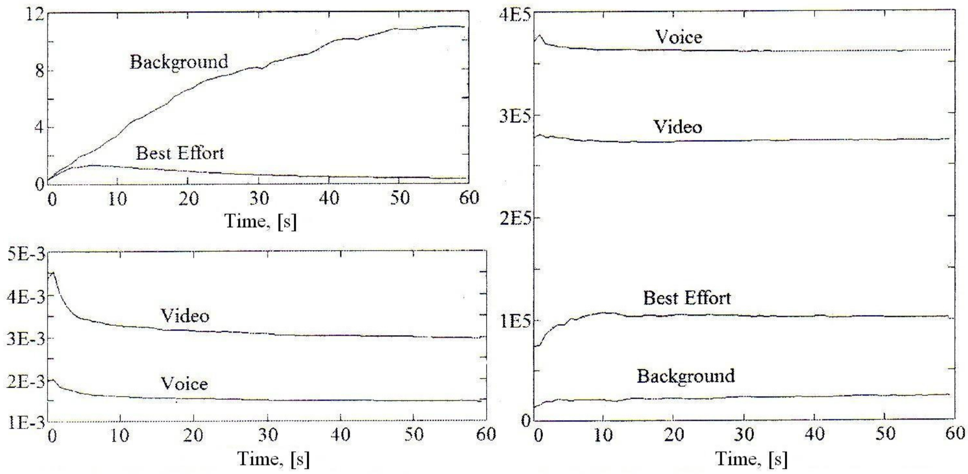

Fig. 4 – The EDCF scenario: Media Access Delay, [s], (left) and Throughput, [bps], (right).

From Fig. 4 one can see that the EDCF system has a good QoS for voice and video applications, with low delay values (0.0015 s for voice, 0.003 s for video) compared to the best effort transmissions with delays of 0.5 s, and to background applications with higher delay values.

Throughput varies in the same manner as media access delay.

3.2 Simulation for Comparative Analysis between DCF and EDCF

The second scenario (DCF) uses the same PHY and MAC parameters as in the EDCF case. The results are shown in Figs. 5 and 6.

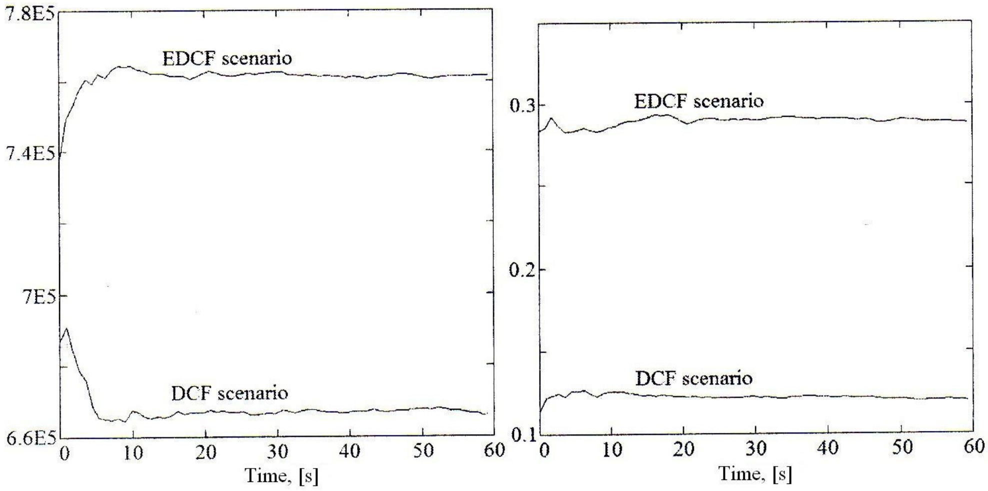

Fig. 5 – DCF *vs*. EDCF: Throughput, [bps], (left) and Retransmission Attempts, [pkt], (right).

The throughput in EDCF is higher than in DCF with up to 14%. The retransmission attempts in DCF protocols are lesser than in EDCF protocol, justified by the goal of the real-time application prioritization of EDCF.

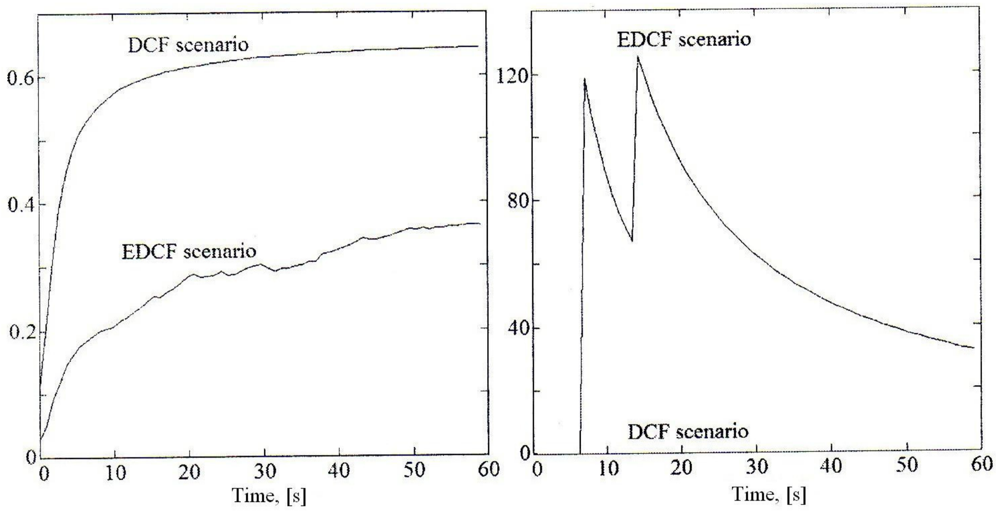

Fig. 6 – DCF *vs*. EDCF: Media Access Delay, [s], (left) and Data Dropped, [bps], (right).

EDCF suffers lesser media access delay than DCF. The reason of varying Data Drop gradually in EDCF is the service differentiation which provides priority based scheme to handle different kind of data.

4. Conclusion

The results obtained from the simulations shows that the MAC protocol EDCF provides an efficient mechanism for service differentiation and hence provides quality of services to the 802.11 wireless LAN. This improvement comes at a cost of a decrease in quality of the lower priority traffic up to the point of starvation. The acquisition of the radio channel by the higher priority traffic is much more aggressive than for the lower priority. In the EDCF mechanism more collision will be expected comparing to DCF. But in terms of QoS, for delay sensitive applications (VoIP and Video Conferencing), EDCF outperforms DCF.

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MANAGEMENTUL CALITĂȚII SERVICIILOR BAZAT PE NIVELUL MAC ÎN REȚELELE IEEE 802.11

(Rezumat)

Pentru a aprecia calitatea serviciilor oferite utilizatorilor unei rețele WLAN 802.11 s-au folosit metricile: debit, număr de retransmisii, întârziere a accesului la mediu şi probabilitate de abandon. S-a folosit programul de simulare a rețelelor, OPNET Modeler, pentru simularea a două scenarii, unul utilizând protocolul DCF, altul EDCF. În cazul analizei protocolului EDCF atenția a fost îndreptată asupra funcționării diferitelor categorii de acces. Rezultatele obținute indică faptul că protocolul EDCF are performanțe superioare protocolului DCF în a furniza calitate serviciilor pentru aplicațiile în timp real, precum cele de voce sau de videoconferință, datorită posibilității diferențierii şi prioritizării serviciilor prin acest protocol.