Dynamic TXOP configuration for Qos enhancement in IEEE 802.11e wireless LAN

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Abstract: **This paper presents a study on transmission opportunity (TXOP) mechanism of the new MAC protocol described in the IEEE 802.11e supplement to the standard. A simple algorithm for dynamic configuration of TXOP limit is proposed for the contention channel access mode, called Enhanced Distributed Channel Access (EDCA). The proposed scheme aims to define dynamic rules for TXOP duration adjustment in multimode IEEE 802.11e networks in order to improve system efficiency and provide better QoS provision.**

1. INTRODUCTION

Due to great popularity and implementation simplicity of the IEEE 802.11 Wireless Local Area Network (WLAN) standard, and in order to provide an enhanced and differentiated management of different application types, new working groups emerged investigating possible improvements to the legacy standard. Specifically a Task Group, called "e", (TGe) was formed with the idea of providing Quality of Service (QoS) in the WLAN. It has already elaborated various drafts of their proposal. Their work is mainly concentrated on development of new medium access control (MAC) protocol for efficient bandwidth sharing and support for QoS sensitive applications like Voice over IP (VoIP) or video streaming.

The extension of the legacy MAC, proposed by TGe, introduces new mechanism to the MAC layer, enhancing QoS management and providing QoS guarantees to QoS aware applications. Namely Hybrid Coordination Function (HCF) is suggested to operate with two access types: Enhanced Distributed Channel Access (EDCA) and HCF Controlled Channel Access (HCCA) [1]. Both new operation modes are compatible with the legacy IEEE 802.11 DCF and PCF schemes and provide different QoS provisioning methods.

These advances in QoS support within IEEE 802.11 WLAN allow it to be considered as one of the radio access technology of future heterogeneous network as demonstrated in [2]. Consequently, one QoS Basic Service Set (QBSS) of IEEE 802.11 WLAN, operating at infrastructure mode, is considered in our studies.

In this paper we evaluate the performance enhancement achieved by using the transmission opportunity (TXOP) scheme, which modifies the standard transmission procedure by allowing multiple packet transmission on single channel access. Accordingly, a station is allowed to send a number of consecutive packets limited by the duration of allocated TXOP. Therefore, lack of an efficient configuration of the TXOP duration may result in wasteful bandwidth sharing and may have negative influence on delay, jitter and throughput performance of the system. To solve this issue we propose a new dynamic configuration algorithm that enhances the accuracy of TXOP duration estimation.

The rest of the paper is organized as follows: Section 2 introduces enhancements to the legacy MAC as proposed in IEEE 802.11e draft [1]. The comprehensive study of EDCA – TXOP scheme is presented in Section 3. The developed dynamic configuration algorithm of TXOP is described in Section 4. Simulation analysis of proposed scheme is given in Section 5. Finally, the conclusions follow in Section 6.

2. ENHANCED IEEE802.11E MAC

Within the IEEE 802.11e draft [1] two new access modes are incorporated: contention based (CP) called EDCA and contention free (CFP) called HCCA. The EDCA copes with QoS limitations of the Distributed Coordination Function access mechanism of the legacy MAC as described in [3].

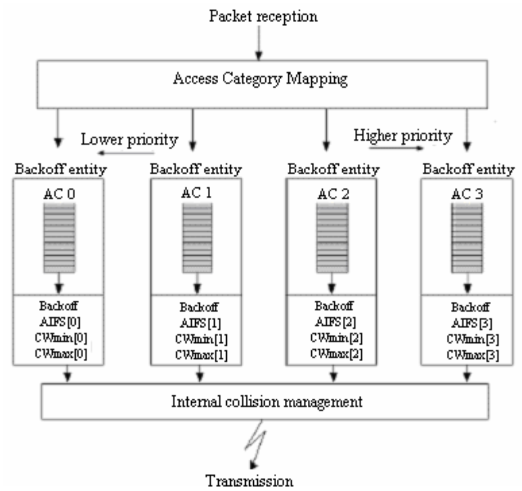

Figure 1 - EDCA access mode

The proposed enhancements are based on introduction of the Access Categories (AC) concept, with their independent backoff entities to provide service differentiation. Each station supports four ACs with different QoS expectations.

Consequently, the incoming packets are mapped to corresponding AC depending on their QoS requirements as shown in Figure 1. Prioritization in this access mode is reached by assigning different values of following contention parameters to each AC:

AIFS – Arbitration Interframe Space that defines the free time interval before backoff stage. It is at least equal to the DIFS interval of legacy MAC. The value of AIFS may be enlarged by Arbitration Interframe Space Number (AIFSN) and is given by equation (1). Smaller values of AIFS correspond to higher priority.

$$AIFS[AC]=SIFS + AIFSN[AC] * aSlotTime >= DIFS \qquad (1)$$

CW – Contention Window with its minimum and maximum size that provides the range of possible backoff defer slots before starting the transmission. Similarly, with smaller maximum and minimum range higher priority is achieved.

TXOP – Transmission opportunity duration that specify a maximum time a station can designate on packet exchange. Thus, the larger TXOP duration the greater channel occupation possible.

The main principles of EDCA access are similar to those of DCF. Each AC, after detecting the medium idle for an AIFS time, starts decrementing its backoff counter and when reaches zero starts transmission. If in a given station, two or more ACs finish their backoff at the same time instant then the so called virtual collision take place. In such situation the AC with the highest priority is allowed to transmit whereas lower priority ACs behave as if they experience a "collision" and thus they need to increment their CWmax range.

The HCF controlled channel access mechanism uses a QoS-aware centralized coordinator, called hybrid coordinator (HC) to provide QoS guarantees. Similarly to the Point Coordination Function (PCF), the HCF defines a superframe that starts with a beacon frame followed by CFP and CP periods. During CFP, the channel access is managed by a polling mechanism (according to a scheduler defined in HC), normally located in AP, and based on traffic specification (TSPEC) provide by each flow [1]. During CP the channel access mechanism is defined by the EDCA rules. However, HC is allowed to access the medium at any time, owing to its higher priority. In our work we are mainly concerned with EDCA access mode.

3. TXOP SCHEME

The concept of packet bursting for CSMA/CA based networks was first proposed in [4] as a packet frame grouping scheme to improve the system performance when small packets are transmitted. This suggestion is included as an optional mode in the draft of IEEE 802.11e [1] and is referred as TXOP Bursting mechanism.

The principle of TXOP bursting is to allow, for the station that won then channel access, the transmission of multiple packets. This mechanism is characterised by two parameters: the start time and the duration. The duration parameter specifies the time that the station could devote to the packet exchange sequence, including data packet and its corresponding acknowledgement. Both parameters start time and duration depend on the access mode: HCCA or EDCA. Within controlled medium access HCCA mode start time and duration of TXOP limit are managed by HC that schedules poll message to a station for starting burst transmission and specifies its duration. In contention based mode, EDCA, the maximum size of the burst is also controlled by HC. However, by default, the maximum burst size has a constant value, which is obtained by each station from a QoS parameter set element allocated in the beacon frame. Since EDCA mode is contention based, the burst start time is defined by backoff algorithm executed independently at each station. In addition, during TXOP period only packets from the same AC are sent and successive packets are separated by SIFS interval. Since SIFS interval is used for packet separation, the other stations cannot gain channel access as they have to wait at least DIFS interval. The station ends its TXOP burst in three cases: if it does not have more packets within the winning AC, if there is not enough free space for the next packet exchange (QoS Data + ACK) or if packet transmission fails.

The TXOP mechanism introduces great enhancement because the contention overhead is shared between all the packets allocated within the burst. Therefore higher efficiency and lower delays can be obtained, such as discussed in references [5], [6]. Moreover, the TXOP option also increases fairness between queues of the same AC and different packet size as medium occupation time is characterized by TXOP duration.

4. TXOP DYNAMIC ADJUSTMENT ALGORITHM

As mentioned before in Section I, this paper concerns with infrastructure mode of IEEE 802.11e. Therefore, the AP is considered a node with a major packet concentration as it dispatches whole downlink traffic. Moreover, usually the downlink traffic is superior to the uplink traffic due to the traffic asymmetry of the envisaged services. Consequently, in order to satisfy QoS requirements of each flow it is vital to assure adequate values of access parameters of the AP. Accordingly for each AC, the developed dynamic TXOP limit adjustment algorithm varies the burst duration based on the average number of packets allocated in AP queues (one queue per AC is assumed). The average number of packets is considered instead of simple measure of actual queues length of AP's buffers as the actual queue length represents instantaneous measure which may be affected by burst packet arrivals and hence cannot characterise objectively queue size as a function of channel status. The rationality of the proposed heuristic algorithm follows:

The TXOP limit can be calculate by means of formula:

$$TXOP\_Limit = N * Pq\_Length \quad (2)$$

where:

Pq_Length – is the average packet length computed as the time needed for MSDU transmission over physical layer used,

N – is an average number of packets in a queue;

It can be clearly noticed that the equation (2) achieves the maximum when the maximum MSDU size allowed by IEEE 802.11 standard is used with, the slowest, 1Mbps physical rate and the average number of packets in a queue is equal to the buffer size. Therefore in some congestion situations TXOP duration could reach very high limits allowing packets from some AC to occupy entire channel bandwidth. Hence to limit the maximum TXOP value we can restrict it to:

- the buffer size, as proposed in [7], or
- the value obtained when a given collision probability is achieved and hence obtain the optimum TXOP assignment for a given conditions.

The above algorithm was implemented in a software simulator in the following way. To obtain the average number of packets in a queue, the AP estimates it by means of equations (3) and (4):

$$estimated\_size_n = estimated\_size_{n-1} + actual\_q\_size \quad (3)$$

where:

estimated_size – is an estimation based on its previous value and actual queue size calculated with every packet arrival to corresponding transmission queue,

n – is an arrived packet's index,

actual_q_size – is an actual size of a queue to which packet arrives including this packet

$$N = \left\lceil \frac{estimated\_size_n}{n\_total} \right\rceil \quad (4)$$

being:

n_total - a the total number of arrived packets to corresponding transmission queue during estimation interval,

N – the average number of packets in a queue estimated every beacon interval, in our case every 100 ms.

After each estimation of the value of N, the parameters n, estimated_size and n_total are initialized to zero, thus with the first packet arrival estimated_size1 = actual_q_size = 1.

Applying above mentioned algorithm to our WLAN software simulator, let us first check how good the estimated number of packets in a queue is. Figure 3 compares the number of packets (obtained as a time average of a number of packets in the queue when a packet arrives or leaves the queue, referred to as a real number) in the AP voice queue (marked in blue colour) with the estimated average of a number of packets in the AP voice queue, obtained by means of the proposed algorithm (marked in red).

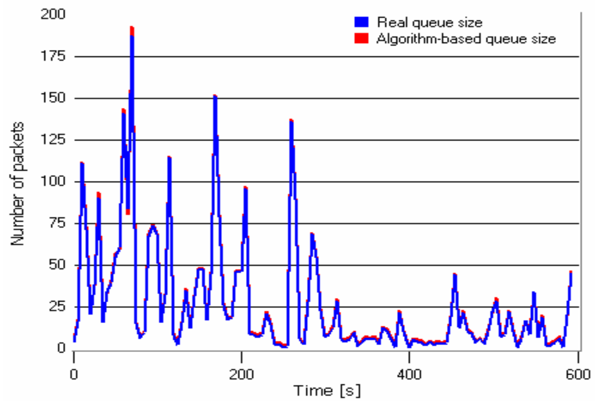

Figure 3 - Comparison of the real number of packets in AP voice queue and the number obtained by proposed algorithm

The slight difference between these two graphs is due to the fact that the proposed algorithm only computes the queue size when a packet arrives.

Once, the average number of packet is obtained, the TXOP limit is calculated according to the equation (2).

5. SIMULATION RESULTS

To analyse performance of the dynamic TXOP adjustment algorithm an isolated QBSS is considered with the following services: voice, video and web. The voice traffic is generated as G.729 A/B bidirectional VoIP application with packet size of 60 Bytes and transmission rate of 24kbps. To model the video stream a Group of Pictures (GOP) of 13 frames was used, as proposed in Everest project [8] assuming 25 frames per second and 128 kbps transmission rate in downlink and 16 kbps in uplink. The traffic model for web flows considers exponential interarrival time between packets and truncated Pareto distribution for packet size with 256 kbps average transmission rate in downlink and 64 kbps in uplink direction. For each AC, each type of traffic, one queue is considered.

Additionally, some adaptation referring to packet length, considered in our algorithm, was introduced. Explicitly, the Pq_Length parameter is computed assuming the maximum packet length permitted by IEEE 802.11 MAC layer and a 11Mbps PHY layer. This assumption normalizes the duration of TXOP parameter and avoids large TXOP intervals when nodes are beyond the range of the fastest PHY layer. Moreover, when using 11Mbps transmission rate, further benefit for the shortest packets is reached as initially more than one packet may be sent on single channel access, thereby reducing backoff overhead. Furthermore, as TXOP parameter is updated every beacon interval (100ms) it does not respond rapidly to burst packet arrivals and with the packet length adjustment this effect may be mitigated.

5.1 Non-saturation case

In this case, 6 voice, 4 video and increasing number of interactive stations all of them working with 11Mbps PHY layer were studied. Given that analysed WLAN system is one of the possible RATs for heterogeneous system, it is consider that some admission control, [9], limiting the number of terminals, is adopted, Therefore, the maximum number of interactive users is limited. The proposed algorithm is applied only to the access categories with time restricted services, namely to AC3 and AC2. For AC1, a constant value of TXOP of 0 is used allowing only one packet transmission per channel access.

Table 1 - EDCA contention parameters

AC	AIFSN	CWmin	CWmax	TXOP-default [s]
1	2	31	1023	0.000
2	2	15	31	0.006
3	2	7	15	0.003

Through this set-up, the system performance with default and dynamic configuration of TXOP limit with stations working at fixed 11Mbps PHY later, were compared. The EDCA contention parameters used in the simulations are included in Table 1.

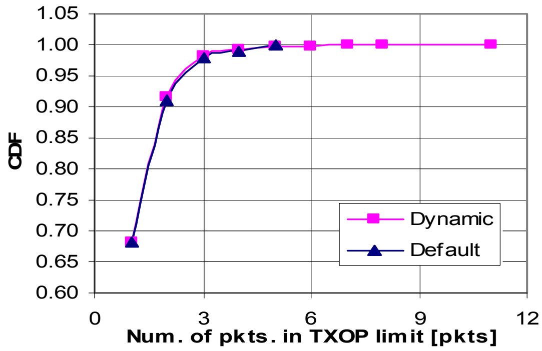

Figure 4 - CDF of number of transmitted packets within TXOP limit from AP's AC3 queue.

Figure 4 and Table 2 show that in a steady state situation there is quite a small difference in system performance when using default constant or dynamically tuned TXOP limit values.

Table 2 - AP's MAC delay for 95% of cases with dynamic and default configuration of TXOP

	Collision rate (coll/s)	AP's MAC Delay for 95% of cases(s)		
		AC3	AC2	AC1
Dynamic	111	0.00448	0.01056	0.73803
Default	115	0.00466	0.00964	0.82606

The small gain of dynamic tuning observed for AC3 in Table 2 is obtain due to the fact that, in some infrequent situation, with dynamic tuning a station is allowed to send more packets than it can send with the default configuration (maximum of 5 in analysed case) what can be seen in Figure4. Consequently, these results denote that using default constant TXOP values is satisfactory when all stations use the same physical layer.

5.2 Saturation case

However, the assumption of an invariable PHY layer is not realistic as usually in the same QBSS region the stations will work with diverse PHY layers depending on received signal strength. Therefore, when low bit-rate modes are used, the duration for transmitting packets through the radio channel may increase significantly, resulting in longer channel occupation and causing the growth of the number of stored packets in station's queues. For instance, for packet of size of 1024 octets, the PHY layer switch from 11Mbps to 1 Mbps represents an increment in the bandwidth demand of approximately the 7 times.

These circumstances were encompassed in a second study where the same system set-up is considered. However, now the interactive stations, after successful admission to the system, switch their PHY layer to the slowest bit-rate (1Mbps) to model the possible channel condition variations.

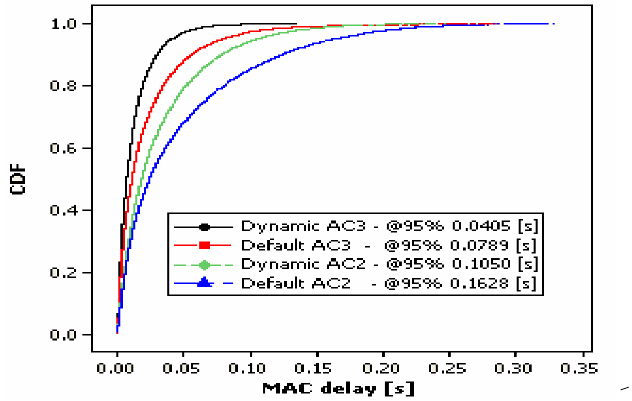

Figure 5 - CDF of AP's MAC delay for default and dynamic case for AC2 and AC3 queues

The MAC delay experienced by packets in AP's queues is shown in Figure 5. From the figure, the obtained results clearly demonstrate that dynamic adjustment of TXOP limit outperforms constant allocation. Moreover, it can be noticed that the decrease of AP's MAC delay can reach nearly up to 50%, for 95 % of cases, for voice traffic (AC3).

Accordingly to what has been previously mentioned, due to the delay introduced by packets from interactive stations (with the slowest link), the number of packets in queues augments in comparison to the non-saturation case, see Figure 6. Moreover, when comparing queue size for default and dynamic tuning of TXOP limit for saturation case we clearly see that for voice traffic (AC3) 50% reduction in queue size, for 95 % of cases, is obtained. Achieved gain is due to the greater and more flexible size of TXOP bursts that are beneficial in situation when some congestion occurred in the system resulting in higher packet accumulation in station's queues. The number of packets sent within the dynamically tuned and default TXOP limit is shown in Figure 7. From this figure we find that maximum size of TXOP limit for default set-up allows only bursts of 5 packets for voice application and 6 packets for video application. In contrary, with dynamic tuning of TXOP in 10% of cases for AC2 higher than 6 packets limit is used and in 20% of cases for AC3 higher than default packet limit is applied. These higher TXOP thresholds allow to cope with packet accumulation due to some congestion problems. Therefore, the developed algorithm allows preserving the delay characteristics of the time restrictive application if temporal saturation peaks are reached.

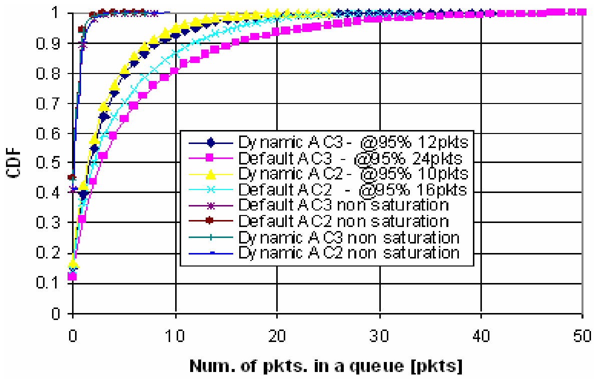

Figure 6 - CDF of number of packets in AP's AC2 and AC3 queues for default and dynamic case

Moreover, due to better channel efficiency higher total aggregate throughput for the evaluated saturation condition for interactive traffic, best effort service, is reached with dynamic algorithm (176.3 kbps) than with default TXOP values (166.3 kbps).

6. CONCLUSION

In this paper a new algorithm for dynamic configuration of TXOP limit in multirate IEEE 802.11e network is presented and its performances are analysed and compared with default configuration. It was demonstrated that proposed algorithm improves system performance, sustains QoS expectative and controls temporal saturation peaks of high priority traffics in situations of light congestion.

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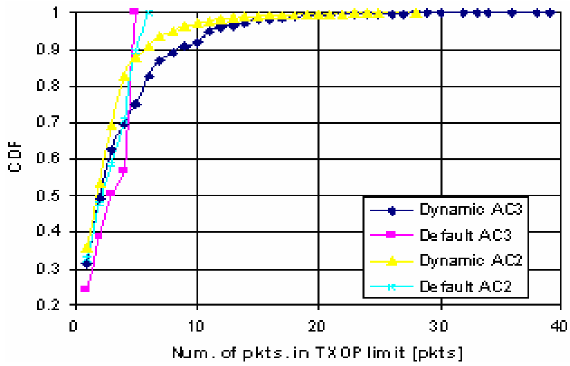

Figure 7 - CDF of number of transmitted packets within TXOP limit from AP's AC2 and AC3 queues.

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