

Impact of Best Effort Frame Bursting in IEEE 802.11 Networks

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Abstract—Wireless LAN strongly prioritizes high priority traffic over low priority best effort traffic. This causes reduced access to the medium for low priority traffic and under some conditions even leads to starvation. To compensate the throughput reduction of low priority traffic, we propose frame bursting in this paper. That means low priority traffic is sent infrequently, but many frames may be sent in a burst. Our simulation results show that the throughput of the low priority best effort traffic class can be significantly increased without disrupting high priority traffic.

Index Terms—IEEE 802.11, TXOP Limit, burst adaptation

I. INTRODUCTION

THE still increasing number of IEEE 802.11 networks is a success story. In contrast to traditional wireless networks, Wireless LAN based on the IEEE 802.11-2007 standard [1] is cost-effective, self-organizing, and self-configuring. However, the downside is the absence of real *Quality of Service* (QoS) support. Although it enables service differentiation, it does not provide QoS guarantees. One reason for this is the lack of a load control for Wireless LAN. Furthermore, resource efficiency has severely decreased through the service differentiation extension due to the use of small and static contention windows. As a result, time-varying loads cause heavily varying contention levels leading to an inefficient channel use. In the worst case, traffic performance is degraded and QoS requirements cannot be met.

A first step towards an efficient resource allocation for Wireless LAN was proposed in [2]. The mechanism called *Dynamic Contention Window Adaptation* (DCWA) dynamically adapts the contention windows according to the current channel contention level at runtime. The *Access Point* (AP) chooses an appropriate contention window according to the number of retransmissions measured at the high priority queues and broadcasts them through beacon frames. Thus, Wireless LAN resources available to high priority flows significantly improve, become more robust, and are still protected. However, as a result, the performance for high priority traffic increases but the low priority traffic flows are prone to starvation.

A way to prevent low priority traffic from starvation without disturbing high priority traffic is frame bursting for low priority best effort flows. In this paper, we take a look at the influence of such a frame bursting scheme and we show that frame bursting effectively mitigates the low priority best effort flow starvation with regard to voice traffic QoS requirements. Using extended transmission bursts, best effort flows considerably benefit by an increased channel utilization through reduced

protocol overhead and by the use of free resources not needed for voice traffic.

This work is organized as follows. Section II introduces the Wireless LAN channel access and in Section III the work related to burst adaptation mechanisms is reviewed. Section IV and Section V show the influence of different burst sizes on the high priority traffic class for a saturated and a realistic traffic model. Finally, Section VI concludes this paper.

II. OVERVIEW OF THE WIRELESS LAN MAC PROTOCOL

In this section, we introduce two main access mechanisms of the IEEE 802.11-2007 standard and describe how frame bursting can be used.

A. Distributed Coordination Function

The *Distributed Coordination Function* (DCF) is the primary access mode using the CSMA/CA protocol for sharing the wireless medium. Stations which want to transmit a packet compete with each other for medium access and all stations have equal rights. Since Wireless LAN stations are not able to detect a collision on the medium, an acknowledgment scheme is used for that purpose. If no acknowledgment is received by the sending station, it will retransmit the packet. In order to reduce the collision probability on the wireless medium, the stations sense the medium for a period of time called *Distributed Interframe Space* (DIFS) and perform a backoff before transmitting a packet. The backoff is defined by a number of slots which is chosen uniformly distributed from the interval $[0, CW]$. Initially, the *Contention Window* (CW) is set to CW_{min} . Whenever a packet loss occurs, the CW value is increased by $CW' = (CW + 1) \cdot 2 - 1$ until the maximum value CW_{max} is reached. The complete medium access procedure is shown in Fig. 1.

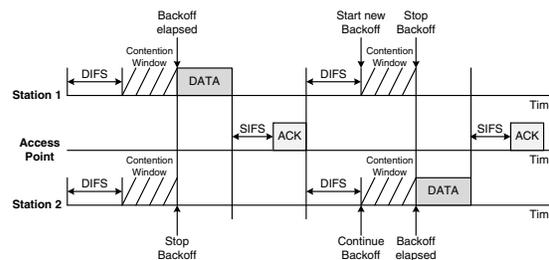


Fig. 1. Medium access example for DCF stations.

B. Enhanced Distributed Channel Access

The DCF is extended by the *Enhanced Distributed Channel Access* (EDCA). In contrast to the DCF, EDCA is based on different priorities. It supports eight different priorities from 0 to 7 as defined in the IEEE 802.1d standard [3]. These priorities are mapped to four *Access Categories* (ACs). The ACs are sorted from AC0 to AC3 with AC3 having the highest priority for medium access. The service differentiation according to these ACs is achieved by varying the amount of time a station senses the channel to be idle before starting the contention window (*Arbitration Interframe Space* (AIFS)), the length of the contention window to be used (CW_{min} and CW_{max}), and the duration a station may transmit after it acquires the right to transmit called *Transmission Opportunity limit* (TXOP Limit).

The length of the AIFS[AC] can be calculated as follows, with AIFSN[AC] as the number of slots.

$$AIFS[AC] = AIFSN[AC] \cdot aSlotTime + aSIFSTime$$

Using the *Extended Rate PHY* (ERP) layer at 2.4 GHz, aSlotTime is 9μs and aSIFSTime is 10μs. As lower priorities use a larger AIFS, a certain prioritization can be reached. A further prioritization is reached by the backoff procedure. Using EDCA, each access category has its own CW_{min} and CW_{max}. The settings for our simulation studies with 54 Mbps at 2.4 GHz can be seen in Table I. As we can see, the highest priority class is assigned a CW_{min} of 3 and a CW_{max} of 7 while the lowest priority class is assigned the values 15 and 1023. This will lead to different mean contention window sizes. Clearly, a station with a lower mean contention window gets access to the medium more often.

TABLE I
DEFAULT EDCA PARAMETER SET USING ERP AT 2.4 GHz.

AC	CW _{min}	CW _{max}	AIFSN	TXOP Limit
0	15	1023	7	0
1	15	1023	3	0
2	7	15	2	6.016 ms
3	3	7	2	3.264 ms

C. Frame Bursting using the TXOP Limit

Besides the prioritization scheme, the TXOP Limit is also introduced with EDCA. The TXOP Limit describes the time a station is allowed to transmit multiple frames after it gained access to the medium. It is expressed in multiples of 32 μs like shown in Table I. The TXOP Limit duration values are advertised by the Access Point in beacon frames. A TXOP Limit field with a value of 0 indicates that a single *MAC Service Data Unit* (MSDU) may be transmitted at any rate for each *Transmission Opportunity* (TXOP).

The transmission of a frame burst is shown in Fig. 2. The data packets and acknowledgments are only separated by *Short Interframe Spaces* (SIFs). It is obvious that the use of a transmission burst optimizes the link utilization because the backoff scheme does not have to be performed for every

packet. However, the downside of this scheme might be longer delays and a higher collision probability during the contention phase.

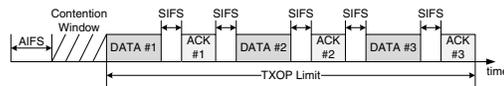


Fig. 2. One transmission burst.

III. RELATED WORK

Burst adaptation mechanisms for Wireless LAN mainly focus on burst adaptations of real-time traffic flows. Analytical models to show the impact of the TXOP Limit are presented in [4]–[7]. The first two papers present an analytical model showing the influence of the transmission burst size when using the DCF. The latter two papers analyze the impact of the TXOP Limit for the EDCA. However, the limit is set similar for every service class. It is claimed that the size of the TXOP Limit should be set carefully to prevent low priority traffic from starvation.

Simulation studies of the TXOP Limit are presented in [8]. Similar to the analytical papers, it is claimed that the TXOP Limit should be set proportional to the buffer size. Majkowski and Palacio [9] on the other hand do not only measure the buffer size, but also take the transmission speed into account and introduce a new TXOP Limit mechanism called *Enhanced TXOP* (ETXOP) to optimize the system throughput. The mechanism is validated through OPNET simulations. Another OPNET simulation is performed by Liu et al. [10]. In this paper the TXOP Limit is adjusted according to estimations of the incoming video frame size. The duration of a burst is then set to the time necessary to transmit the video frames pending in the buffer and additional frames expected by the estimator. Cranley et al. [11] present another TXOP Limit study for video streaming. However, it is also claimed that the TXOP Limit is not suitable for audio streams because of the constant bit rate streams.

None of these paper analyze the performance effects of the TXOP Limit if it is just used for the best effort traffic class. In this paper we focus on a burst adaptation scheme for this traffic class. Our goal is to set the TXOP Limit for the best effort class as large as possible to ensure a high throughput without disrupting high priority traffic flows.

IV. THROUGHPUT IMPROVEMENT THROUGH FRAME BURSTING

In this section, we explore the throughput improvement for *Best Effort* (BE) traffic through frame bursting. Frame bursting, expressed by the parameter TXOP Limit, allows a station to transmit several data packets during each won *Transmission Opportunity* (TXOP). When setting the TXOP Limit to more than one data frame for BE traffic, more medium resources are granted to BE traffic. The influence of frame bursting on voice traffic and the throughput improvement of BE traffic is analyzed in this section.

A. Simulation Settings

To study the impact of the TXOP Limit[BE] extension we use the OPNET Modeler simulation environment [12]. First, we configure a saturated traffic model. The intention behind this is to get an idea about the general system behavior. A saturated station, no matter if it is a voice or best effort station, always has a packet of size 1500 Bytes to transmit. We set the TXOP Limit[Voice] to one *MAC Service Data Unit* (MSDU) for all simulation scenarios. The differentiation is realized by extending the TXOP Limit[BE] to the values listed in Table II.

TABLE II
TXOP LIMIT[BE] EXTENSION.

TXOP Limit[BE]	
Duration (ms)	#MSDUs per burst
0.320	1
0.640	2
1.280	4
3.200	10
6.400	20

The duration of a complete transmission cycle of a single MAC packet including SIFS and its ACK takes approximately 0.32 ms. A TXOP Limit[BE]=6.4 ms means that once a BE station has won a TXOP, it has the right to transmit frames for 6.4 ms which corresponds to 20 packets. Furthermore, in order to support more stations in the system, we increased the contention windows to $CW_{min}=63/CW_{max}=127$ for voice traffic and to $CW_{min}=255/CW_{max}=16383$ for best effort traffic according to Pries et al. [2].

B. Impact of Frame Bursting on the Throughput

In order to study the impact of frame bursting on the throughput, we configure a scenario with 16 Voice and 16 BE stations. Fig. 3 shows the average throughput where each curve is plotted as a function of TXOP Limit[BE]. While increasing the TXOP Limit[BE] up to 50 MSDUs per burst, the total throughput increases up to 34.2 Mbps which is a gain of 40% relative to 24.5 Mbps for a burst size of 1. The explanation of the flattening of the total throughput curve is that performance degradation due to collisions is mitigated through long burst sizes and reduced contention. This effect becomes saturated at a certain point. This was also observed by the authors in [4].

Altogether this shows that the parameter TXOP Limit[BE] is an extremely powerful means to realize throughput optimization. Fig. 4 shows the average throughputs of voice and

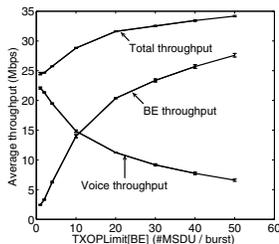
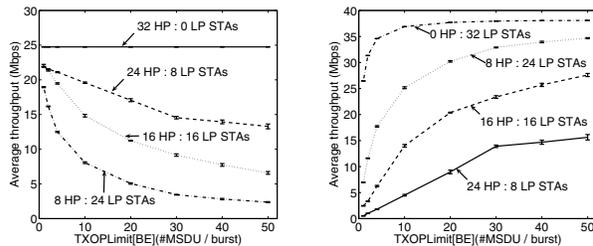


Fig. 3. Impact of an extended TXOP Limit[BE] on the total throughput and on the throughput distribution among high priority and low priority traffic.

BE stations for the same scenario, but as a function of the traffic mix. The decrease in voice throughput and the increase in BE throughput, as observed before, comprises all traffic mix constellations.

Most interesting are the differences among the set of curves and their progression with the traffic mix. In general, the fewer voice stations and the more BE stations are in the scenario, the lower the voice and the higher the BE throughput. For TXOP Limit[BE] values of 20 and 30 the decline in voice throughput and the increase in BE throughput becomes tremendous. At that point, the contention window prioritization of voice traffic is far outweighed by TXOP Limit[BE] prioritization of BE traffic.

A main result of the throughput analysis is that applying a TXOP Limit[BE] extension increases the capacity for BE traffic. This capacity increase is realized independently of the traffic mix. A further result is that BE throughput prioritization with TXOP Limit[BE] works very effectively and can counterbalance negative throughput impacts through voice contention window prioritization. It is a useful means to distribute available resources among traffic classes.



(a) Throughput of voice stations. (b) Throughput of best effort stations.

Fig. 4. Impact of an extended TXOP Limit[BE] and of the traffic mix on voice and best effort throughput, 32 station scenario.

V. IMPACT OF FRAME BURSTING ON THROUGHPUT, DELAY, AND DELAY VARIATION IN A REAL SCENARIO

In this section we assess the applicability of a TXOP Limit[BE] enlargement under more realistic conditions to draw conclusions about its benefits in practice.

A. Simulation Settings

For the following simulations we set up high priority voice stations and low priority best effort stations. A voice station uses the ITU-T G.711 [13] voice codec with a packet size of 640 bits and an interarrival time of 10 ms. This voice codec is used because it is the most prevalent voice codec. However, tests with other voice codecs have shown a similar behavior. A best effort station downloads files from the Access Point using TCP with a packet size of 1500 Bytes. The performance figures presented here refer to scenarios with 20 best effort stations, while the number of voice stations varies from 5 to 30. In order to support a maximal number of voice stations the DCWA algorithm from Pries et al. [2] was used. The DCWA adapts to the contention level of the voice queue and controls both the contention window of AC Voice and AC BE, and the latter is linearly controlled with AC Voice. Their initial

values are set to $CW_{min}[AC\ Voice]=3$, $CW_{max}[AC\ Voice]=7$, $CW_{min}[AC\ BE]=15$, and $CW_{max}[AC\ BE]=1023$.

The duration of an individual simulation is 200 s. The stations start equally distributed within [0 s;50 s]. Thus, the first 60 s are regarded as transient phase and are not considered for the statistics. The performance figures are generated on the basis of 30 replications, applying a 95 % confidence interval. In order to study the influence of best effort frame bursting, we simulate the above described scenario with the TXOP Limit[BE] values provided in Table II.

B. Cell Capacity for DCWA with Frame Bursting

Fig. 5 shows the average throughput of all best effort stations. Best effort average throughput is here a function of the number of voice stations, which extends from 5 to 30. We observe that with an increasing number of voice stations, best effort average throughput steadily declines because voice stations are strictly prioritized through smaller contention windows. With 30 voice stations, Wireless LAN operates close to its capacity limit. The capacity limit is reached when the burst size causes the medium resources to be shifted from voice to best effort traffic, severely deteriorating voice traffic QoS. In detail, through the use of a large TXOP Limit[BE], the arrival rate of voice packets surpasses the sending rate of the voice access category, leading to buffer overflow and hence to dropped voice packets at the Access Point. We

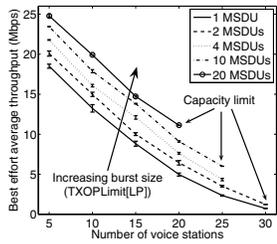
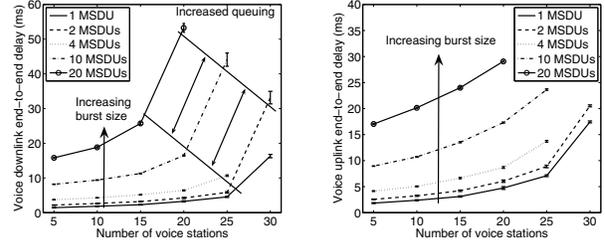


Fig. 5. Impact of an extended TXOP Limit[BE] on the best effort throughput.

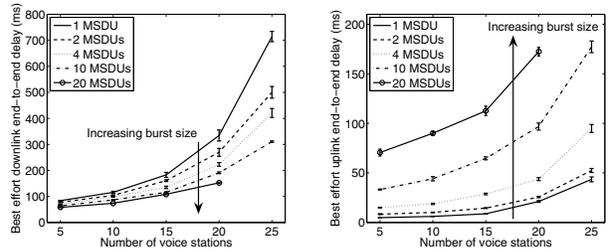
recognize that best effort traffic achieves as much bandwidth as possible in dependency of the amount of prioritized voice traffic. Furthermore, it is shown that using extended frame bursts is very beneficial to increase best effort throughput performance. However, enlarging the burst size of the best effort access category must be done with care as we will see in the next paragraphs. Frame bursting affects voice and best effort traffic in different ways. Voice delay suffers in both directions, from the Access Point to the station and vice versa. Best effort delay on the other hand only suffers on the uplink. On the downlink, the delay is reduced. For our simulation we consider the end-to-end delay. The end-to-end delay consists of the queuing and the contention delay. Furthermore, we differentiate between downlink and uplink delays.

Fig. 6(a) and Fig. 6(b) display the end-to-end delay for voice traffic of both downlink and uplink. We observe that with an increasing number of voice stations, both downlink and uplink delay increase. First, this is due to larger medium busy times when more stations are transmitting. Second, this is due to the DCWA control which effects larger contention windows,

resulting in larger backoff times, when more stations compete for medium access. We can recognize a severe impact of the burst size on the voice traffic delay: with increasing burst size, uplink and downlink delays increase. In case of the downlink, we notice the heavy increase in delay whenever Wireless LAN is close to its capacity limit. Then the MAC buffer is filled up with packets, increasing the queuing delay of each packet.



(a) Voice downlink end-to-end delay. (b) Voice uplink end-to-end delay.



(c) BE downlink end-to-end delay. (d) BE uplink end-to-end delay.

Fig. 6. Impact of voice traffic and TXOP Limit[BE] on voice and best effort end-to-end delay.

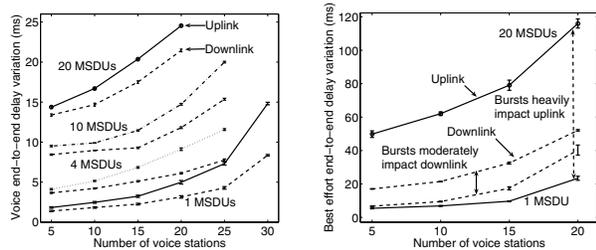
As mentioned above, best effort delay benefits and suffers from best effort bursts at the same time. On the one hand, it benefits because transmitting more frames than one per TXOP translates to almost zero contention time for every packet which is additionally transmitted per burst. Further, it reduces the time a best effort packet has to wait in the MAC buffer. We affirm this by Fig. 6(c), which shows the best effort downlink end-to-end delay. We recognize that an increasing burst size leads to a significant decrease in delay. On the other hand, the uplink of best effort traffic suffers from an increased burst size as we can derive from Fig. 6(d). The reason for this is that a station of a best effort connection basically does not take advantage of the frame bursting feature as the Access Point does, because for the first, queuing is irrelevant, for the latter it is relevant.

Finally, we take a look at the end-to-end delay variation. The IETF [14] defines delay variation of a pair of packets within a stream of packets as the difference between the one way delay of these packets. Assume P1 and P2 are two consecutive MAC packets, and the time stamps at their source and destination stations are S1, S2 and D1, D2, respectively. Then, the delay variation is calculated as follows:

$$\text{delay variation} = |(D2 - D1) - (S2 - S1)|$$

Fig. 7(a) exhibits the increase of the voice end-to-end delay variation for both the uplink and the downlink, when increasing the number of voice stations, and when increasing the best effort burst size. We notice the difference between uplink and downlink. This phenomenon has two reasons. First, the voice downlink benefits from frame bursting. With an increasing number of voice stations, queuing at the Access Point rises, resulting in downlink frame bursts with several voice packets. Consequently, bursts of voice frames on the downlink reduce contention delay, and therefore reduce the variability of the packet delay. The second reason is the unfairness between stations and Access Point described in Pries et al. [15]. The contention delay of the voice downlink transmissions is much smaller compared to the uplink contention delay because the Access Point competes against fewer transmissions than the stations. This results in a larger end-to-end delay variation of the uplink flows.

The results of best effort end-to-end delay variation can be seen in Fig. 7(b). It also exhibits differences among downlink and uplink. The use of frame bursting leads to significantly increased variability of the uplink delay. Larger burst durations force other stations to wait longer before they can access the medium. The impact on the downlink delay variation is twofold. On the one hand, transmission bursts increase the contention delay variation for best effort traffic in the same way as for voice traffic. On the other hand, frame bursting decreases the downlink delay variation for best effort traffic because the first packet within a burst suffers long contention delays while the other packets face a minimum contention delay of only a single SIFS time of $10\mu s$. The contention delay variation decreases with increasing burst size because then most best effort packets have a short contention delay. This has a major impact on the end-to-end delay variation.



(a) Voice end-to-end delay variation. (b) BE end-to-end delay variation.

Fig. 7. Impact of voice traffic and TXOP Limit[BE] on voice and best effort end-to-end delay variation.

VI. CONCLUSION

In today's Wireless LANs the prioritization of high priority traffic might lead to starvation of low priority best effort traffic flows. In order to counteract to this, we proposed frame bursting for low priority traffic to increase its throughput while controlling the loss of prioritization for high priority traffic. We showed that high priority traffic is still prioritized over low priority traffic whose throughput is significantly increased. Furthermore, the best effort throughput improves because of an increased Wireless LAN resource efficiency which is due

to reduced protocol overhead and due to reduced contention. Best effort frame bursting can effectively counterbalance the negative impact of contention window prioritization on best effort traffic.

Simulations of voice and best effort stations in a Wireless LAN cell showed that increased frame bursts lead to more residual capacity for best effort traffic but also reduce the number of supportable voice stations that enjoy prioritized transmission. The limitation of the number of voice stations is caused by too large queuing delays for typical voice applications. We suggest to set the TXOP Limit between 1.28 ms and 3.2 ms in order to significantly increase the best effort throughput without disrupting high priority traffic.

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