On the Unfair Channel Access Phenomenon in Wireless LANs

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***Abstract*—This paper shows that the relative collision probability for packets in Wireless LAN 802.11 networks decreases with increasing load offered by the respective station. This denotes a clearly unfair channel access which is important to be aware of, e.g., when collision probabilities are measured and used for reactive control of contention windows. We model the unfair channel access phenomenon analytically and semi-analytically for bidirectional constant bit rate and unidirectional TCP traffic and compare the results with those from simulations.**

***Index Terms*—802.11, DCF, EDCA, Unfairness, Wireless LAN, channel access, collision probabilities**

I. Introduction

The *Medium Access Control* (MAC) of Wireless LAN is based on *Carrier Sense Multiple Access with Collision Avoidance* (CSMA/CA) whose collision avoidance is realized by a truncated binary exponential backoff algorithm whereby the minimum and maximum backoff time is given by the minimum and maximum contention window parameters CWmin and CWmax. The *Access Point* (AP) chooses these values and propagates them to all stations. These parameters control the frequency of their transmission attempts which has a direct impact on packet collision probabilities and utilization of the medium. Therefore, these values must be carefully chosen. The standard proposes to use a set of fixed values, but many papers also suggest dynamic adaptation of these parameters [1]–[4]. These parameter adaptations are based on measurements at the AP assuming fair resource sharing between the stations and the AP.

In a recent paper [5] we also presented a method for dynamic adaptation of CWmin and CWmax based on measurements of packet collision probabilities. Thereby, we discovered that the packet collision probabilities measured by the AP are not the same as those measured by the stations. Therefore, we averaged the measurement values obtained from the AP and all stations to get a representative estimate of the collision probabilities. In this paper, we investigate this unfair channel access phenomenon, explain it by a mathematical model, and validate the analytical results by means of simulations.

The remainder of this work is organized as follows. In Section II we review work related to other unfairness problems in Wireless LAN. Section III gives an overview of Wireless LAN MAC protocols and Section IV introduces the unfair channel access phenomenon. In Section V simulation results are presented showing the unfairness between Access Point and stations for different traffic models. Section VI shows how the unfair channel access phenomenon is even intensified with the introduction of burst transmissions. Finally, conclusions are drawn in Section VII.

II. Related work

A large amount of papers have been published on the Wireless LAN channel access. In this section, the papers addressing any kind of unfairness in Wireless LAN are presented. The first part covers general unfairness papers and the second part focuses on unfairness of TCP over Wireless LAN.

Gilles Berger-Sabbatel et al. [6] analyze the short-term fairness in Wireless LAN and its impact on the delay. An ad-hoc network consisting of saturated sources without any hidden or exposed stations is considered. Using the *Jain fairness index*, the authors show by an analytical model, simulations, and measurements that the *Distributed Coordination Function* (DCF), the primary medium access function of the IEEE 802.11 standard, is short-term fair. Furthermore, they claim that papers [7], [8] consider the IEEE 802.11 standard as short-term unfair because these papers use the Wavelan CSMA/CA access method [9] for their simulations without noticing that the access method differs from the DCF.

In [10] and [11], the authors observe a significant unfairness between downlink and uplink flows when the DCF or the *Enhanced Distributed Channel Access* (EDCA) from the IEEE 802.11e [12] standard are used in a Wireless LAN with an Access Point. It is claimed that the DCF allows equal utilization of the medium and thus, if the downlink has much more offered load than the uplink, the downlink becomes the bottleneck. Grilo et al. [11] use three traffic models, a voice model, a video model, and an HTTP traffic model to show that as soon as the utilization increases, the Access Point becomes the bottleneck both with the DCF and the EDCA. To solve the problem, the Access Point should use a polling based access mechanism. As an alternative solution, Kim et al. [10] propose a mechanism where the Access Point uses a shorter interframe space duration compared to the stations before accessing the shared medium.

The TCP unfairness between uplink and downlink connections in Wireless LANs is presented in [13]–[15]. It is shown for different traffic models that the downlink flows tend to starve. Park et al. [13] claim that the starvation is caused by both the TCP-induced and the MAC-induced unfairness.

Pilosof et al. [14] propose to solve the problem by increasing the buffer size at the Access Point to avoid packet loss due to buffer overflow. Similar to this paper, Thottan et al. [15] identify the equal access probabilities of the Access Point and the stations as the reason for the TCP unfairness. In contrast to Pilosof et al. [14], they show that an increased buffer size does not solve this problem and propose an adaptive EDCA parameter set.

Another paper about TCP unfairness is presented by Blefari-Melazzi et al. [16]. They claim that downstream TCP connections suffer because of the arising congestion and corresponding packet losses happening in the downlink buffer at the Access Point. Furthermore, for upstream TCP connections, the Access Point has to transmit the TCP acknowledgments which are delayed and lost, because the Access Point cannot access the medium with a priority higher than other stations. Leith et al. [17] look at the TCP fairness for upstream flows too. They have shown that the TCP acknowledgment will be delayed using the standard DCF access mechanism. They propose a scheme of how to prioritize the Access Point by using a different parameter set for the medium access according to the IEEE 802.11e standard. The proposed mechanisms are tested in an experimental scenario and the results can be found in [18].

Furthermore, TCP unfairness observations are made by Jian and Chen [19]. Using ns-2 simulations they show that the fairness between the nodes depends on the distance and the difference between carrier sensing and transmission range. They propose a *Proportional Increase Synchronized Multiplicative Decrease* (PISD) mechanism to ensure not only fairness but also weighted fairness in CSMA/CA networks.

All the papers focus on the discrepancy of delays and buffer overflow probabilities experienced by the Access Point and the stations. To the best of our knowledge, a related issue that has not yet been investigated is another kind of unfairness resulting from different collision probabilities. Interestingly, the latter unfairness favors the Access Point which is contrary to the former. In order to demonstrate this unfairness, we first give an overview of the Wireless LAN MAC protocols and introduce the fairness considerations within a small simulation scenario. Afterwards, the results of the simulation studies are presented using UDP voice traffic and TCP traffic flows. These results are validated by analytical models.

III. Overview of the Wireless LAN MAC Protocol

In this section, we introduce two main access mechanisms of the IEEE 802.11-2007 [20] standard.

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 are chosen uniformly distributed from the interval $[0, CW]$. Initially, the *Contention Window* (CW) is set to CWmin. Whenever a packet loss occurs, the CW value is increased to $CW' = (CW + 1) \cdot 2 - 1$ until the maximum value CWmax is reached. An example of the medium access procedure is shown in Fig. 1.

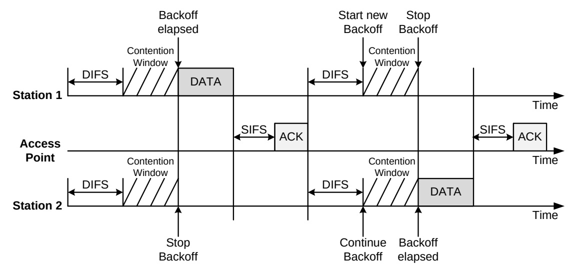

Fig. 1. Medium access example for DCF stations.

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. Eight different user priorities from the IEEE 802.1d standard [21] are mapped to four *Access Categories* (ACs) as shown in Fig. 2. 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 (CWmin and CWmax), and the duration a station may transmit after it acquires the right to transmit (*Transmission Opportunity limit* (TXOPLimit)).

The length of the AIFS[AC] is calculated as

$$\mathit{AIFS[AC]} = \mathit{AIFSN[AC]} \cdot \mathit{aSlotTime} + \mathit{aSIFSTime} \quad (1)$$

with *AIFSN[AC]* as the number of slots. Using the *Extended Rate PHY* (ERP) layer at 2.4 GHz, aSlotTime is $9\mu s$ and aSIFSTime is $10\mu s$. As lower priorities use a larger *AIFS*, a certain prioritization can be achieved. The backoff procedure further supports the prioritization. Using EDCA, each AC has its own *CWmin* and *CWmax*. The settings for our studies with 54 Mbps at 2.4 GHz can be seen in Table I. The highest priority class has a *CWmin* of 3 and a *CWmax* of 7 while the lowest priority class has values of 15 and 1023. This leads to different mean contention window sizes. Clearly, a station with a lower mean contention window gains access to the medium more often.

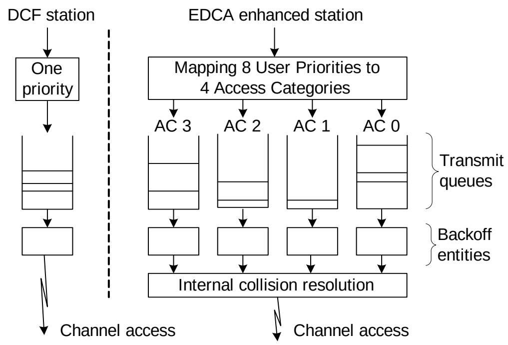

Fig. 2. Reference model of the DCF and of the EDCA.

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

AC	CWmin	CWmax	AIFSN	TXOPLimit
0	15	1023	7	0
1	15	1023	3	0
2	7	15	2	3.008 ms
3	3	7	2	1.504 ms

C. Frame Bursting using the TXOPLimit

The TXOPLimit is another feature introduced with the EDCA. The TXOPLimit 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 as shown in Table I. The TXOPLimit duration values are advertised by the Access Point in beacon frames. A TXOPLimit field with a value of 0 indicates that a single packet may be transmitted at any rate for each *Transmission Opportunity* (TXOP).

The transmission of a frame burst is shown in Fig. 3. The data packets and acknowledgments are only separated by *Short Interframe Spaces* (SIFSs). 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 disadvantages of this scheme are longer delays and higher collision probabilities during the contention phase.

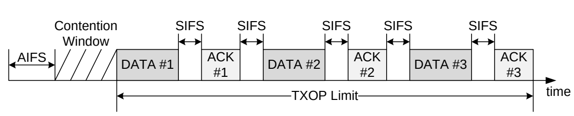

Fig. 3. One transmission burst.

IV. INTRODUCTION TO THE UNFAIR CHANNEL ACCESS PHENOMENON

Equal contention access parameters for both the AP and the stations suggest that the channel access among stations and the AP is fair in terms of collision probabilities. To investigate this assumption, a simulation is configured using the OPNET Modeler [22] simulation environment with the IEEE 802.11g Wireless LAN model. 23 stations communicate with the Access Point using the ITU-T G.711 [23] voice codec with a packet size of 640 bits and an interarrival time of 10 ms.

Fig. 4 depicts the average collision probability of the scenario during the steady-state phase. The packet collision probabilities of each station are averaged over an interval of one second and the system is in steady-state after about 45 seconds.

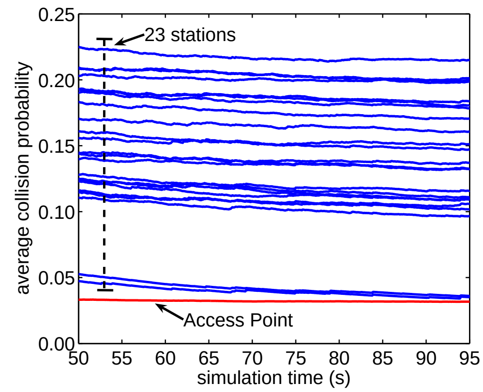

Fig. 4. Unfairness between Access Point and stations.

The collision probability measured at the AP is just below 5 % and the lowest in the network. The collision probabilities of the stations range from around 5 % up to over 20 %. The reason for the different collision probabilities of the stations lies in the phase patterns. An example for a phase pattern is shown in Fig. 5. As the voice packets follow a deterministic arrival process with an interarrival time of 10 ms, the collision probabilities of each station depend on the start time of the voice conversation. In the figure, four stations receive their voice packets from the upper layer almost at the same time and thus compete against the other three stations for medium access. This clearly results in higher collision probabilities of these four stations compared to other stations competing only against one station or against no other station at all.

The difference in the collision probabilities of the AP and the station can be traced back to the unfair channel access. A random station competes against 22 stations and the Access Point for channel access when all phases are random. On the other hand, the Access Point competes against 23 stations. It seems that every network entity has to compete against 23 others. However, when considering the number of packet transmissions, the AP competes against 23 transmissions (one

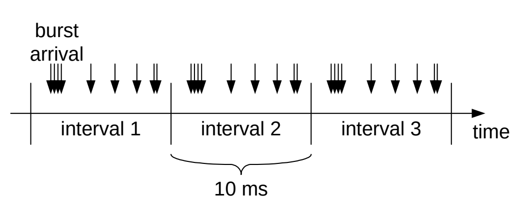

Fig. 5. Phase pattern illustration of voice traffic.

from each station) and each station has to compete against 45 packet transmissions (22 from the other stations and 23 from the AP). In other words, the probability of a frame collision upon a channel access of a station is significantly higher compared to the collision probability of the AP. This explains the different collision probabilities of a single station and the Access Point seen in Fig. 4. Nevertheless, this unfairness explanation just holds when the stations are not saturated.

V. Unfairness of the DCF

The simple simulation scenario has shown the unfairness between voice stations and Access Point in terms of collision probability. In this section, we will try to explain this unfair channel access phenomenon by an analytical model for the voice traffic scenario. The results are compared with a simple MATLAB simulation and a detailed OPNET simulation. The MATLAB simulation includes the CSMA/CA mechanism without regarding extensions of the DCF or influences from other layers. In contrast, the OPNET simulation includes the complete DCF with all its extensions and simulates all layers of the ISO/OSI protocol stack.

A. Unfair Channel Access Using Voice Traffic

To explain the unfair channel access, a simple analytical model is used. First, the access probabilities of AP and stations are calculated without considering packet retransmissions due to collisions. These access probabilities are then used to calculate the collision probabilities. The resulting number of retransmissions from the collision probabilities are used to recalculate the access probabilities. Thus, a repeated substitution of collision probabilities and access probabilities is applied to get an approximation of the collision probabilities.

Let us now define the algorithm in more detail. As in the previous section, we consider a scenario with N stations and one Access Point. Stations and Access Point are communicating symmetrically. Let $A = 10\,ms$ be the frame period of the voice application. Further, let M be the number of slots between two packet arrivals. According to the IEEE 802.11g standard, the length of a single slot is $9\,\mu s$. The slots can either be used for packet transmissions, interframe spaces, or contention.

Assume that all stations and the AP are able to transmit their packets within the interval A. This means that every station transmits one packet during this interval and the AP transmits N packets. So, during interval A, $2 \cdot N$ packets are transmitted. X slots are needed to transmit one packet, including ACK, *Short Interframe Space* (SIFS), *Distributed Interframe Space* (DIFS), and the packet transmission itself. This means that during interval A, the remaining $M - 2 \cdot N \cdot X$ slots are available for contention. The parameters are illustrated in Fig. 6.

Now, the access probability and collision probability can be calculated using a repeated substitution. The iteration starts by calculating the access probabilities assuming that no collision occurs on the channel. This results in the probability

$$p_s = \frac{1}{M - (2N-1)X} \tag{2}$$

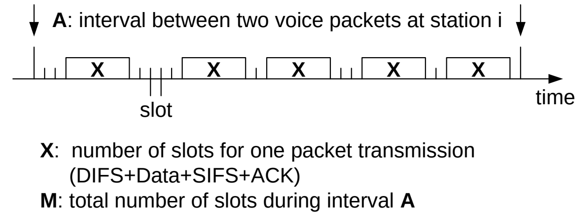

Fig. 6. Parameter illustration of the analytical model.

that a station accesses a given slot and the probability

$$p_{AP} = \frac{N}{M - (2N-1)X} \tag{3}$$

that the Access Point accesses the medium. The numerator shows the number of packets that have to be transmitted and the denominator describes the number of available slots. One transmission is subtracted because the station or Access Point whose access probability is calculated has not yet transmitted its packet. Having defined the initial access probabilities of the iteration process, the independent collision probabilities can be calculated as

$$q_s = 1 - (1 - p_{AP})(1 - p_s)^{N-1} \tag{4}$$
$$q_{AP} = 1 - (1 - p_s)^N \tag{5}$$

where q_s is the collision probability of a station and q_{AP} is the collision probability of the Access Point. As the Access Point competes against all stations, the collision probability is calculated using the access probability of the stations. A station on the other hand competes against all other stations and against the Access Point. Therefore, we have to take both, the access probability of the stations excluding ourselves and the access probability of the Access Point into account.

Using the collision probabilities the access probabilities can be redefined, but before, the mean number of collisions have to be estimated. The number of retransmissions needed for a successful packet reception is calculated using the geometric distribution. Thereby, the mean number of required retransmissions lead to

$$X_s = E(Geo(q_s)) = \frac{q_s}{1 - q_s} \tag{6}$$

for the stations and to

$$X_{AP} = E(Geo(q_{AP})) = \frac{q_{AP}}{1 - q_{AP}} \tag{7}$$

for the Access Point. The transmission of N packets results in an N-fold geometric distribution or in

$$Y_s = E(NegBin(q_s, N)) = \frac{N \cdot q_s}{1 - q_s} \tag{8}$$

for all stations and in

$$Y_{AP} = E(NegBin(q_{AP})) = \frac{N \cdot q_{AP}}{1 - q_{AP}} \tag{9}$$

for the Access Point. Assuming that two or more packets collide, the mean number of collisions K can be defined as

$$K \cong \left\lceil \frac{\frac{N \cdot q_s}{1-q_s} + \frac{N \cdot q_{AP}}{1-q_{AP}}}{2} \right\rceil \quad (10)$$

where the denominator is the minimum number of colliding packets of all stations and the Access Point. From this approximation of the mean number of collisions, the remaining number of slots available for contention with $M-(2N-1+K)X$ are recalculated and the new probability that a station accesses a slot is determined as

$$p_s = \frac{\frac{q_s}{1-q_s} + 1}{M - (2N - 1 + K)X} \quad (11)$$

$$p_{AP} = \frac{N\frac{q_{AP}}{1-q_{AP}} + N}{M - (2N - 1 + K)X} \quad (12)$$

Finally, we can iterate between q and p, using Equation (2) and Equation (3) as the initial access probabilities.

In order to validate the results from the analytical model, we have performed simulations using MATLAB and OPNET. The parameters for the simulation and the analytical model are shown in Table II.

The results from the analytical model and the MATLAB simulation are illustrated in Fig. 7. The 95 % confidence intervals result from 20 simulation runs with different phase patterns. The x-axis shows the number of voice stations and the y-axis illustrates the collision probabilities averaged over all stations. Two observations can be made from this experiment. First, it reveals that the analytical model and the simulation fit well. The second observation is that both the analytical model and the simulation reveal the unfairness between the Access Point and the stations. For 24 stations, the collision probability of the Access Point is around 5.5 % and for the stations around 10.5 %. A further increase of the number of voice stations would lead to false results of the MATLAB simulation, because as it is programmed close to the analytical model, the assumption that all packets can be transmitted within an interval would not hold anymore.

TABLE II
SIMULATION PARAMETERS.

Parameter	Value
Voice frame duration	10 ms
Wireless LAN standard	IEEE 802.11g
Data rate	54 Mbps
Control data rate	24 Mbps
Slot length	9 μs
DIFS time	28 μs
SIFS time	10 μs
CWmin	15
CWmax	1023
Packet length	960 bits+header
ACK length	112 bits+header
Signal extension	6 μs
AP buffer size	4,096,000 bits

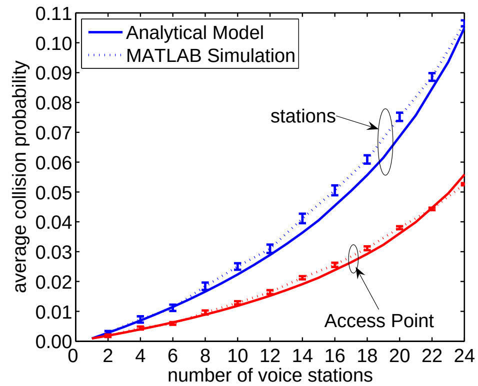

Fig. 7. Unfairness between AP and stations; comparison between a MATLAB simulation and analytical results.

For the OPNET simulation, the number of voice stations can further be increased up to 27. In a scenario with more than 27 stations, the voice connections cannot be established because of a high packet loss. In Fig. 8, the OPNET simulation results are compared to the results from the analytical model. The figure reveals that the collision probability of the analytical model is higher than that of the simulation, especially when the network is not at its capacity limits. This effect results from immediate transmissions. A station can immediately transmit a packet when it is idle for at least DIFS and then receives a packet from the upper layer. In heavily loaded networks, the number of immediate transmissions decrease. This is the reason why the collision probabilities of the analytical model and simulation match well under high load. The figure also shows the unfairness between the Access Point and the stations. For 27 stations, the collision probability of the Access Point is 8.23 % and for the stations 15.68 %.

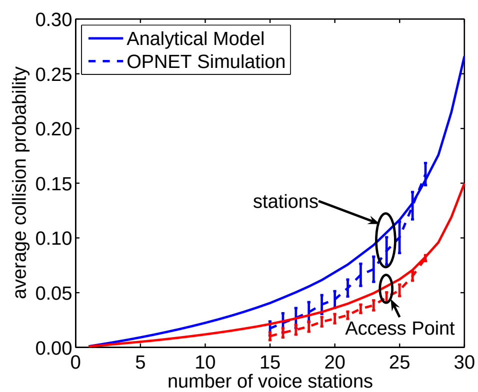

Fig. 8. Comparison of OPNET simulation results with the complete DCF and analytical results.

B. Unfair Channel Access for TCP Traffic Flows

All results, the OPNET simulation, the MATLAB simulation, and the analytical model show the unfairness in Wireless

LAN for bi-directional voice traffic. In this subsection it is evaluated whether the unfairness between stations and the Access Point also occurs for TCP traffic. Therefore, saturated downstream TCP traffic is considered which means that every second TCP downlink packet is acknowledged by the station. The packet size for the downlink packets is set to 1500 Bytes. With all headers, the MAC acknowledgment frame, and the interframe spaces, 37 slots are required for transmitting one TCP packet. TCP acknowledgments require 13 slots for transmission. Further parameters for the TCP simulations are shown in Table III.

The simulations were performed using both OPNET Modeler and MATLAB. Thereby, similar to the voice scenarios, the OPNET simulations account for the complete protocol stack with a detailed TCP model and the DCF extensions and the MATLAB simulation only considers CSMA/CA and a simple TCP emulation. The TCP emulation is a saturated TCP traffic flow where every second TCP packet on the downstream is acknowledged with one TCP acknowledgment on the upstream.

An analytical model for explaining the unfairness phenomenon in a TCP traffic scenario is rather complex. The analytical voice traffic model cannot be used directly, because the packets do not arrive in fixed intervals and especially the TCP acknowledgments from the stations depend on the transmitted packets on the downlink. Therefore, only an approximation is made using an iteration process similar to the voice model. Assuming that the AP is saturated and the backoff is calculated between 0 and *CWmin* in every backoff interval, the access probabilities can be calculated using the following equations:

$$p_s = \frac{1}{2 \cdot N \cdot CW_{min} + 1} \tag{13}$$

$$p_{AP} = \frac{1}{CW_{min} + 1}. \tag{14}$$

The access probabilities of the Access Point result from the fact that the Access Point tries to transmit a packet in every contention phase. In contrast, a station only tries to access the medium in every second frame. N is again the number of stations in the system. From this starting point of the iteration process, the collision probabilities are calculated similar to the analytical voice model:

$$q_s = 1 - (1 - p_{AP})(1 - p_s)^{N-1} \tag{15}$$

$$q_{AP} = 1 - (1 - p_s)^N. \tag{16}$$

Now, the access probabilities for the stations can be redefined as

$$p_s = \frac{\frac{q_s}{1-q_s} + 1}{\sigma \cdot 2 \cdot N \cdot CW_{min} + 1} \tag{17}$$

and the probabilities of the Access Point as

$$p_{AP} = \frac{\frac{q_{AP}}{1-q_{AP}} + 1}{\sigma \cdot CW_{min} + 1}. \tag{18}$$

The factor σ depends on the average number of packets which are transmitted before the Access Point or the stations get a transmission opportunity. As it is not possible to exactly estimate this factor, it is fitted to the curves of the simulation results and set to $\sigma = \frac{2}{3}$.

The collision probabilities from the simulations and analytical model are shown in Fig. 9. On the x-axis, the number of TCP stations is increased from 1 up to 16 and the y-axis shows the average collision probability. The figure reveals that the simulations and the analytical model match quite well. Furthermore, the figure shows that the collision probability of the Access Point is not influenced by the number of stations. In contrast, the collision probability of the stations increase with an increasing number of stations until a constant level of around 14.4 % is reached. If we compare the collision probabilities of the bi-directional voice scenario and this TCP scenario, the unfairness between Access Point and stations becomes even more obvious. The collision probabilities of the stations are 2.6 times higher than the collision probabilities of the Access Point.

TABLE III
PARAMETERS FOR THE TCP SIMULATIONS.

Parameter	Value
Application	saturated TCP
Packet size	1500 Bytes
TCP receive buffer	65535 Bytes
Fast Retransmit	enabled (TCP Reno)
MTU	WLAN (2304 Bytes)
WLAN AP buffer	1024e4 bits
WLAN station buffer	1024e3 bits
CWmin	15
CWmax	1023

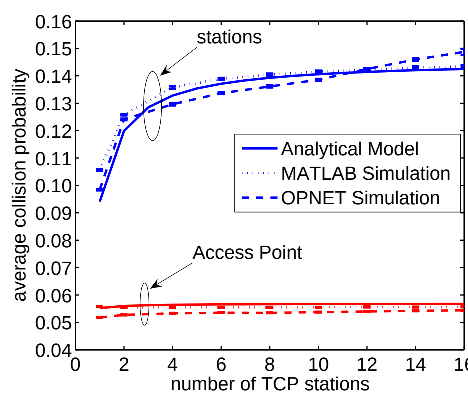

Fig. 9. Unfairness between AP and stations using saturated TCP traffic on the downlink.

VI. UNFAIRNESS OF THE EDCA

With the introduction of the IEEE 802.11e standard and the TXOPLimit, the unfairness between stations operating at different loads changed. The TXOPLimit defines the time a station is allowed to transmit packets in a row after it gained access to the medium. The packets are only separated by the acknowledgment frame and a short interframe space. For our scenario, this means that the Access Point can transmit more than one packet, up to all N packets for the N stations, after it gained access. Comparing the results from the previous section, the access probability and collision probability of the Access Point decrease. This in turn leads to the effect that more stations can be supported because the wireless medium is better utilized. However, the unfairness between stations and Access Point increases.

A. Influence of the TXOPLimit on Voice Traffic

This time, the unfairness is shown by means of OPNET simulations only, as it is rather complex to create a simple model to show the influence of the TXOPLimit on the fairness. The parameter settings for the simulations have been set to the values specified in Table II and the TXOPLimit for the voice queue is set to 1504 μs. With these settings, a maximum number of 32 voice stations can be supported.

The results in Fig. 10 reveal on the one hand that the collision probability in both directions decreases compared to the results from Fig. 8. On the other hand, the unfairness between Access Point and stations has increased. While the average collision probability of the Access Point increases only slightly with an increasing number of stations, the collision probability of the stations increases from around 2 % for 20 stations up to 23 % for 32 stations.

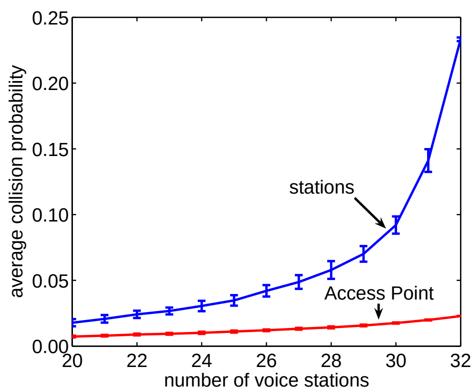

Fig. 10. Unfairness between AP and stations with a TXOPLimit of 1504 μs.

B. Unfairness in terms of contention delay

In order to show that not only the collision probabilities differ between the Access Point and the stations, we take a look at the unfairness in terms of contention delay. The contention delay starts when the packet is at position zero of the queue and ends when the acknowledgment frame is successfully received. The contention delays are simulated with the same settings as in Subsection VI-A. Fig. 11 depicts the average voice contention delay. To compare the contention delay of the stations and the Access Point, we do not consider the contention delay of individual packets but the contention

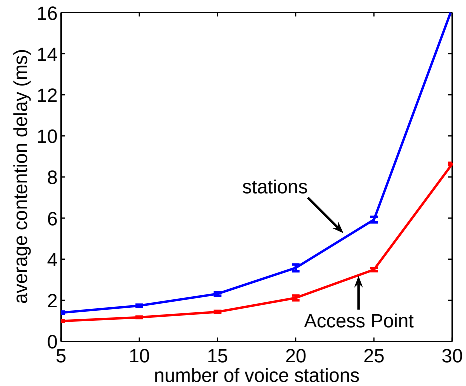

Fig. 11. Contention delay unfairness between Access Point and stations using a TXOPLimit of 1504 μs.

delay of individual transmission opportunities. Doing this, bursting effects from Fig. 10 are excluded and thus, solely the medium access time is considered. The prioritized Access Point exhibits contention delays that are up to 7 ms lower than the corresponding contention delay of the stations.

There are two reasons for the lower delay at the Access Point. The first reason is that only up to 13 packets fit into one transmission burst and if 30 stations are active in the system, the Access Point has to transmit at least 3 bursts. With the transmission of these 3 bursts, the collision probability of the stations is larger than the collision probability of the Access Point, see Equation (2) and Equation (3). The second reason is that the transmission of a packet from the station is delayed for at least the TXOPLimit if the Access Point has gained access prior to the station.

C. Influence of the TXOPLimit on TCP Traffic

Finally, the influence of the TXOPLimit parameter is evaluated for TCP traffic flows; this time only with OPNET simulations. The TCP traffic model from Subsection V-B is used for the simulations. Fig. 12 exhibits the average collision probabilities for three different settings of the TXOPLimit, one data packet, 1504 μs, and 3008 μs. With a TXOPLimit of 1504 μs, up to 4 TCP packets can be transmitted in one burst after the Access Point gained access to the wireless medium and up to 8 TCP packets can be transmitted in a burst using a TXOPLimit of 3008 μs. Since no block-acknowledgments are used, the Access Point recognizes a collision right after the first packet of a transmission burst is transmitted and will stop the transmission of the following burst packets.

The figure reveals that an increasing TXOPLimit decreases the collision probability for both the Access Point and the stations because the access probability of the Access Point decreases. However, the unfairness between the stations and the Access Point remains the same. Therefore, we can conclude that transmission bursts do not resolve the unfairness phenomenon neither for voice UDP flows nor for TCP flows.

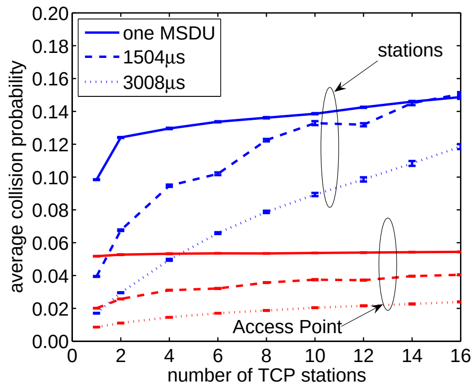

Fig. 12. Impact of the TXOPLimit on the collision probabilities of TCP traffic flows.

VII. Conclusion

In this paper we have shown a new perspective of the unfair channel access in Wireless LAN. In contrast to other publications in this area, which focus mostly on the fairness of TCP streams in Wireless LANs, we took a look at the fairness in terms of collision probability and contention delay on the wireless link. We saw that heavily loaded stations, normally the Access Point, are preferred compared to low loaded stations. This new unfairness was shown by means of simulation and analytical models.

When using the DCF for the channel access, the collision probabilities between Access Point and stations differ up to a factor of 2 for bi-directional voice traffic and up to a factor of 2.8 for TCP traffic flows. With the introduction of transmission bursts, the unfairness is even intensified up to a factor of 6. Besides the different collision probabilities between Access Point and stations, the unfairness can also be observed when looking at the contention delay. In a scenario with high load, the stations need twice as long for accessing the channel in comparison to the Access Point.

This unfairness has to be taken into account when performing load or admission control in Wireless LAN. Measuring the load in terms of collision probability at the Access Point does not reflect the overall situation in Wireless LAN. In further works [5], [24], we presented a method for dynamic adaptation of the contention parameters and the burst size. Taking into account the unfairness between Access Point and stations, the parameters are chosen based on averaged measurement values obtained from the AP and all stations.

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