IEEE 802.11

Wireless Access Methods and Physical Layer Specifications

TITLE: Modified Backoff Algorithms for DCF - Proposed update to Section 5.2.5

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Abstract

This paper describes problems with unequal slot selection probabilities within the backoff-mechanism applied in the DCF and suggestst simple and effective solutions for it.

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1. DFWMAC's Backoff Mechanism

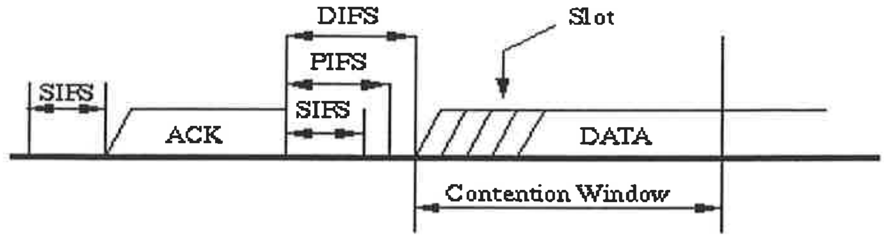


Figure 1: Basic access scheme in the Distributed Coordination Function

Access to the media is provided by the DCF. Once the media has been sensed idle for DIFS and thus been identified as available for transmission a random backoff period within the bounds of the contention window is chosen for an additional deferral time before transmission. The station that selected the shortest random time will gain access for transmission, the others freeze their backoff timer until the winning transmission is finished and wait for the remaining time in the following cycle. That way a station that has been waiting for long to gain access is more likely to win this competition than another that just entered it - the probability of gaining access to the medium increases with the time waited. Collisions only occur if two or more stations select the same slot. They have to reenter the competition with an exponentially increasing CW value i.e. twice CW, 4-times CW if they collide again etc. up to a certain maximum CW value.

2. Probability distributions and their effects

The following section does not attempt to present a complete analysis of the problem but describes it in a qualitative way. We will take a close look at the contention window and the probability that a certain slot within the contention window is selected. We assume a number of stations simultaneously competing for access to the medium. In initial state this scheme results in an uniformly distributed probability function for the selected slots. Each slot is selected with the same probability.**(Figure 2)**

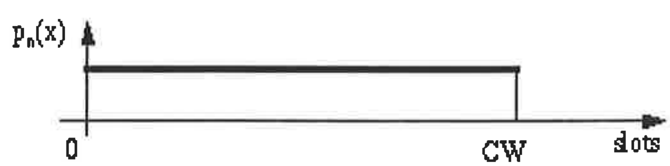


Figure 2: Slot selection probability distribution for initial selection process

In the following cycle all stations that have already been competing for access in the cycle before all have a reduced backoff time, compared to their initially selected value, by $CW_{Selected}$, which is the backoff time that elapsed until the winning station started transmitting. However within this reduced contention window (from 0 to ($CW-CW_{Selected}$)) all slots are selected with the same probability by the remaining stations. If a station newly enters the competition or stations that collided in the previous cycle return back into it, they will choose their slot within the whole range of the contention window with the same probability[2]. This results in a slot selection probability as shown in **Figure 3**, the slots above CW-$CW_{Selected}$ have a significant lower probability to be chosen compared to the slots before this mark.

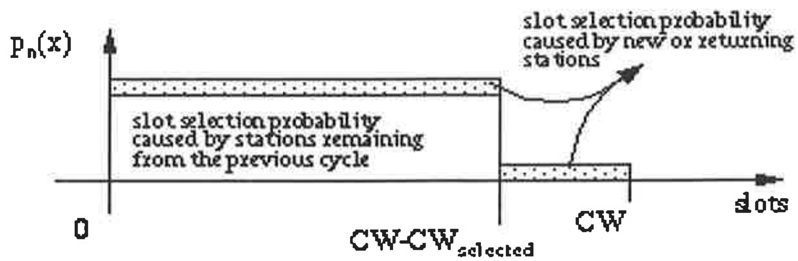


Figure 3: Slot selection probability with stations remaining from previous cycle as well as with new entering stations

Assuming a situation in a wireless LAN under high load, i.e. there are always stations left in the competition as well as there are always stations entering the competition, and in an equilibrium state, we see that slots positioned early in the contention window have a much higher probability to be chosen. The result is a decreasing staircase function for the slot selection probability as shown in **Figure 4.**

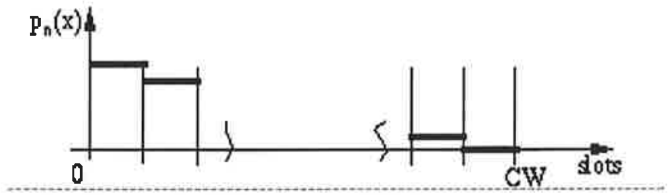


Figure 4: Slot selection probability in equilibrium state

This however causes a very much unwanted effect: slots that are more likely to be chosen also are more likely to be chosen twice or more times, in which case a collision would result. This assumption has been prooved to be valid in our simulations of the slot selection as shown in Figure 5. An uniformly distributed probability for every slot to be chosen is the favored situation in terms of collision avoidance.

3. Modifications of the Backoff Mechanism

There are several possibilities to solve this problem. One method would be to have remaining stations select a new random backoff time within the whole contention window in every cycle again. This however results in a certain possibility that a station waits forever to gain access - there is no mechanism to limit the maximum wait time. We investigated two other approaches to solve the problem, both of them attempt to keep the newly entering stations out of the way of the stations that have lost the previous competition.

[2] Actually, due to the double sized contention window for stations returning into the competition from collision, those stations have only half the probability to choose a slot compared to a newly entering station, but in this context we consider this distinction negligible since both types of stations add qualitatively the same to the resulting probability function, they just differ quantitatively. Our simulations however reflect the increasing CW-size.

3.1. Weighted Selection Probabilities

Our first approach is based on the idea to give the slots different probabilities to be chosen in the initial slot selection process. If stations that arrive new in the competition select slots with higher numbers with higher probabilities, they would not increase the collision probability for the slots with lower numbers. This procedure would keep the new stations out of the way in favor of the stations that have been waiting for access longer already. As we have shown in the previous paragraph with the original DFWMAC scheme we get a constantly decreasing slot selection probability. Therefore the obvious approach is to weight the slot selection probabilities for the initial selection with a constantly increasing probability. Slots that are positioned late in the contention window are selected with higher probability thus giving the slot selection process of newly entering stations the opposite probability function than the one for already competing stations. We experimented with several probability functions, starting from a linear increasing function to functions of higher order. Since the distribution function for all slot selections has to be 1 for x=CW, the slot selection probability function changes into:

$$f(x) = \frac{n+1}{CW^{n+1}} \cdot x^n \qquad (n \geq 0, 1 \leq x \leq CW)$$

For the linearly increasing probability function (n=1) we don't get significantly improving behavior, however we achieve higher throughput with increasing exponents n up to a certain maximum[3]. We got best results with n in the area of 10.

The obvious drawback of this scheme is that even if load is low in the WLAN and thus there would be no need to choose late slots since no stations are waiting for access from previous cycles the late slots are chosen anyway. This causes a slight increase in average access delay but since delay caused by collision adds up much more to the overall delay the reduced collision probability of the modified scheme can be considered advantageous compared to the DFWMAC scheme. (as shown in section 4)

3.2. Load Adaptive Selection

The second approach is using a different method to have newly entering stations preferably select slots that are likely not to have been used so far. The optimal strategy for this scheme would be the following: If the winning slot in the previous competition cycle was at position $CW_{Selected}$ all the other stations that lost this competition cycle will have a slot position below ($CW-CW_{Selected}$). Therefore we restrict newly entering stations in their slot selection process to the slots between ($CW-CW_{Selected}$) and CW i.e. if slot 4 was the winning slot in the previous competition and there are 32 slots overall, newly entering stations only get to chose between slot 29 and 32.

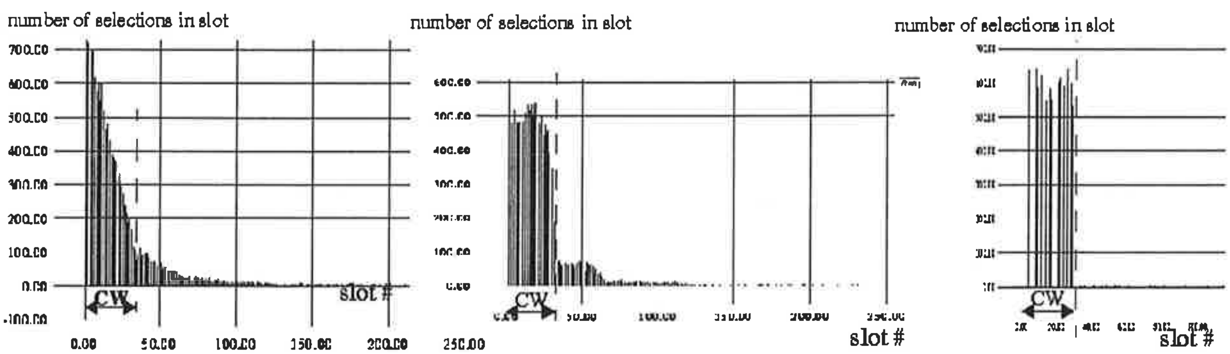
The crucial point in this scheme is the fact that every newly entering station has to have the knowledge about the position of the previously winning slot available. However since stations are in listen mode all the time anyway, if they are not in doze-mode power-saving-state, this monitoring can easily be implemented without adding much complexity. The case of stations in power-saving-mode that do not monitor traffic can be considered to happen significantly less often compared to stations entering from active mode. We can assume that, if the network is running under high load, the winning slot in the previous competition is likely to have been positioned early in the contention

[3] Obviously the DFWMAC scheme represents the case for n=0 in this function.

window since this small backoff time is likely to be the remains of a larger backoff time in the competition cycle before. Early position of the winning slot is a sign of 'rough' competition and can eventually be interpreted as a sign of high load. Our scheme can thus be seen as a load adaptive scheme applying different degrees of access deferral depending on the load.

4. Simulative Results

For our simulations we used PTOLEMY [3]. We simulated a WLAN using DFWMAC's distributed coordination function as the access scheme with a network throughput of 2Mbit/s. Our setup involves 8 stations without hidden terminals (fully meshed network). The channel model is based on the approach described in [4]. The packet sources are simulated as Poisson processes with an attached infinite queue. The packet sizes are read from a trace file of an Ethernet [5]. We simulated with the following fixed values: SIFS=3μs, DIFS=32μs, Slottime=4μs, PHY-Preamble=30byte, CW_min=32Slots, CW_max=256Slots, RTS/CTS switched off. We expect the values for SIFS and DIFS to be higher than the one we chose, once they get fixed. However the effect on the collision rate we described above will even increase with larger values for these times. Below we present the distribution of slot selection for each of the schemes described above.



(Figure 5)

Figure 5: Distribution of slot selection for (from left to right) DFWMAC, weighted scheme, load adaptive scheme,

Our results show a significantly better distributed slot selection probability as can be seen in **Figure 5** in the middle and left graph. Slots above CW are only selected from colliding stations that choose their backoff slot in the enlarged contention window. Therefore the more slots are selected above CW the more collisions have occurred.

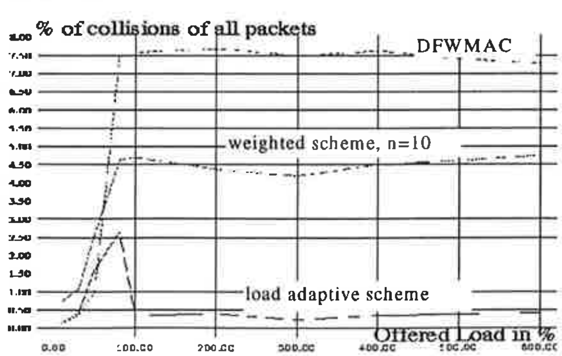


Figure 6: Collision rates vs. load, all three schemes

Compared to the original DFWMAC backoff scheme we get lower collision rates under almost any load condition.**(Figure 6)**

The remarkable result of the above figure is, that considering the high load case, we get almost no collisions in the load adaptive scheme. The lower rate of collisions quite naturally results in a significant increase in throughput and decrease in mean access delay **(Figure 7).**

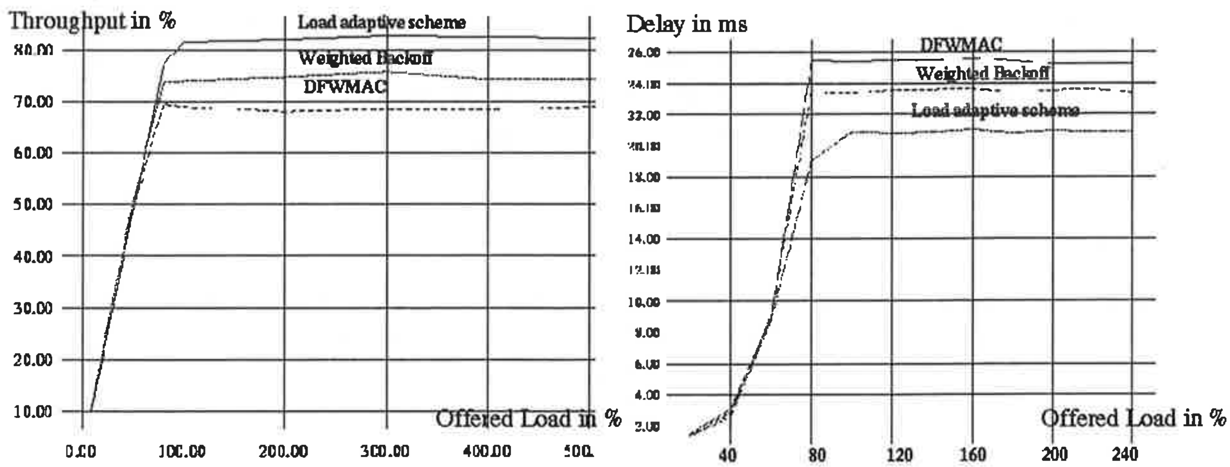


Figure 7: Throughput vs. load, all three schemes, Mean access delay vs. load, all three schemes

The 'ugly', though explicable peak for the collision rate in the lower load range results from the fact that at this point there may be many stations entering the contention phase at one time. If the number of slots to chose from is accidently very small, this may result in a collision. It might therefore be useful if not all stations do have the exact information about $CW_{Selected}$. A possible solution is a strategy where a station only has to remember the number of free slots in its own last attempt to transmit. This strategy would not even require to have the stations listen in the backoff cycle before. A station which did not attempt to send before would have to select a slot from the whole contention window, i.e. DFWMAC is some kind of a "worst case" for our strategy. We performed simulations of this simpler strategy **(Figure 8)**:

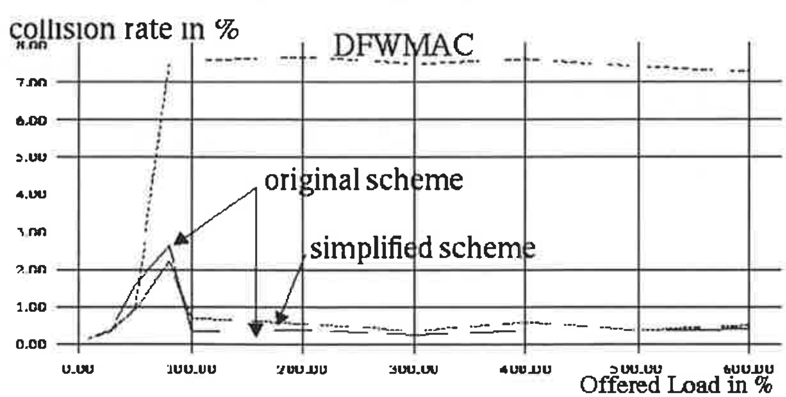


Figure 8: Load adaptive schemes compared to DFWMAC, collision rate in % of all packets

The result shows lower collision rates for the simplified load adaptive scheme than for DFWMAC under **every** load condition. On the other hand, the collision rate in the case of a high load (about 100-300% of the maximum bandwidth) is slightly higher than for the scheme with exact information about the last number of free slots.

All our simulation results obviously depend on the simulation approach, especially on the source modelling. We are currently conducting further simulation on this, using conventional poisson distributed packet sources and traces of an Ethernet [5]. In order to 'flatten' the collision rate curve, our first intention was to work not with the latest number of free slots, but with a mean of the last n cycles. This didn't lead to any significant improvement - the collision rate even increased with n. Nevertheless, this mean seems to be a good measure for the overall net load.

5. Conclusions

As we have shown in the previous sections we can gain up to 20% in throughput and decrease the average access delay at about 15% by applying our modified backoff scheme. Since this gain can be achieved without adding to the protocols complexity or at any other cost we propose to apply the modified, load adaptive backoff scheme to get the free significant improvements of the protocols behavior.

This would change the equation in section

5.2.5 Random Backoff Time into

BackoffTime = (CW-INT($CW_{Selected}$*Random()))*Slot time

where:

CW = An integer between Cw_{min} and Cw_{max}

$CW_{Selected}$ = An integer, which reflects the number of free slots (i.e. the backoff counter) before the last transmission of a packet from the station.

Random() = Pseudo random number between 0 and 1

6. References

[1] Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, Draft Standard IEEE 802.11, P802.11/D1; The editors of IEEE 802.11

[2] S. Saunders: Wireless LANs: Closer to cutting the cord; Data Communications, March 21, 1993

[3] PTOLEMY, anonymous ftp site: ftp.ptolemy.eecs.berkeley.edu, www: http://ptolemy.eecs.berkeley.edu, Copyright © 1990-1995 The Regents of the University of California.

[4] W. Diepstraten, A Wireless MAC Protocol comparison; IEEE 802.11 working paper P802.11-92/51, May 1992

[5] W.Leland et al.: On the self similar nature of Ethernet traffic (Extended version) IEEE Transactions on Networking, Vol. 2, No 1; February 1994