A Saturation Throughput analysis for 802.11e MAC protocol incorporating the Arbitrary Interframe Spacing effect

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***Abstract*— This paper describes a way to include the Arbitrary Interframe Spacing (AIFS) effect in the Enhanced Distributed Channel Access (EDCA) analysis for throughput and delay. The collision probabilities are altered to incorporate the effect of AIFS. The results are compared with other results from the references and with the OPNET simulator. The improvement is shown in the figures. Close match is achieved in most of the cases.**

***Index Terms*— Wireless Local Area Networks, performance analysis, saturation throughput analysis.**

I. Introduction

A new Medium Access Control (MAC) protocol has been recently releashed for 802.11 Wireless Local Area Networks (WLANs), called 802.11e, [**?**]. Specifically, the proposed EDCA mechanism is expected to provide Quality of Service (QoS) to mobile terminals in mesh mode by categorizing traffic into four Access Classes (ACs). A great interest in analyzing this new protocol has risen in the scientific society.

The first backoff analysis for the 802.11 Distributed Coordination Function (DCF) was introduced by Bianchi [1] in 2000. This was later improved in 2002 by Ziouva and Antonakopoulos [2] who proposed the freezing of backoff counters in order to calculate the imposed delay. Finally, Foh and Tantra proposed an improvement [3] in 2005, which achieves better results for DCF performance analysis.

In the meantime, Xiao [4] in 2004 proposed an application of the same analysis for the uprising 802.11e protocol without being able to take into account some aspects that recently appear in the standard. Kong et al. [5] in 2004, proposed a different approach by analyzing the slot time of the protocol in a chain. In [**?**], an improved analysis is presented where two different chains are used to differentiate between the class AC0 and the rest of the classes. However, it seems that the given solution can not be extended to cover cases where AIFS is different for all applications.

In this paper, an improvement of analysis of [4] is proposed in order to produce more realistic results. The aim of the paper is to include the effect of Arbitrary Interframe Spacing using an elegant and easy to use solution. The results of the new analysis are compared with the previous work on this matter and with OPNET simulator results. The rest of the paper is organized as follows. In section II the 802.11e EDCA mechanism is briefly introduced, in section III the proposed analysis is presented, in IV the results are compared to previous works and the paper is concluded in V.

Manuscript submitted November 2, 2005; This work is supported by the OPNET Simulator.

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II. Overview of 802.11e EDCA

The protocol 802.11e is an upgraded version of the legacy 802.11 MAC protocol, [**?**]. Distributed Coordination Function (DCF) and Point Coordination Function (PCF) comprised 802.11 MAC specifications, the first providing distributed access using CSMA/CA with binary exponential backoff whereas the second offering a central controlled polling scheme for use in access point based WLANs. Similarly, the Enhanced Distributed Channel Access (EDCA) (formerly called Enhanced DCF or EDCF) and the Hybrid coordination function (HCF) Controlled Channel Access (HCCA) correspond to the two upgraded versions of the 802.11e. The rest of the paper deals with the EDCA mechanism of 802.11e. An detailed overview of the two protocols can be found in both [4] and [**?**].

EDCA mechanism is similar to EDCF with the exception of three important features, the variable contention window, the Arbitrary Interframe Spacing (AIFS) and the Transmit Opportunity (TxOP), all three of which are used to differentiate between the several ACs. The variable contention window means that the terminals with low contention window values will have to wait smaller amount of time before accessing the channel, which results in greater throughput and less MAC delay. Low AIFS means that the Interframe Spacing before starting the backoff counter will be less than other terminals, resulting in faster backoff count down and further improvement of throughput and delay. Moreover, since all the terminals contend for the channel, the inability of some terminals to access the channel (those with great CW and AIFS values) maximizes even more the efficiency of the rest. In table I, the values of CW and AIFS are shown. Note that the contention window is defined by two values, the $CW_{\min}$ defining the starting contention window and $CW_{\max}$ defining the maximum one.

The variable contention window has been taken into account in all previous works, [4], [5] and [**?**] despite the fact that different approaches have been used. The variable AIFS has been taken into account in [5] and [**?**]. The solution in first

TABLE I
EDCF VALUES FOR PARAMETERS CWMIN, CWMAX, MW AND AIFS[W] OF THE FOUR ACCESS CLASSES.

	AC3	AC2	AC1	AC0
Application	VoIP	Video	Best Effort	Background
w	3	2	1	0
$CW_{\min}+1$	8	16	32	32
$CW_{\max}+1$	16	32	1024	1024
m_w	1	1	6	6
$AIFS[w]$	SIFS+2Slots	SIFS+2Slots	SIFS+3Slots	SIFS+7Slots

is an elegant one, but the markov chain is very complicated and the results seem unrealistic compared to the simulations. The second provides an aproximation to AIFS by using two seperate chains for two different AIFS cases. In this paper we propose a method to cope for any case of AIFS values.

III. PROPOSED ANALYSIS

The analysis is based in the definition of the Markov chain with stationary probabilities $b_{i,j,k,w}$ where i represents the freezing condition (1 for freezed counter and 0 for idle channel), j represents the backoff state ($W_j = 2jW_0$), w is the relationship between the j-th state and the initial state for the w AC) and k represents the backoff counter value, as in [3]. The chain is illustrated for any value of w in figure 2 of [3], as well.

We define the probabilities $p_{0,w}$ and $p_{1,w}$ as the probability, that another terminal is transmitting after an idle period and a busy period respectively, from the point of view of a terminal of the w AC ($w \in \{0,1,2,3\}$). The probabilities that the channel remains idle after an idle period or a busy period are defined as q_0 and q_1 and are the same for all ACs. Therefore, equation (1) of [3] that yields probability of an idle period P_i can be used directly. Equation (2) can easily change by inserting an index w in $b_{i,j,k}$, ψ_j, π_j, W_0, W_1, m, p_0 and p_1 indicating that the analysis is made for the AC w, $W_{j,w}$ and m_w are the minimum backoff value and the number of exponential increases up to the maximum value and they are given in table I for all ACs. The probability of accessing the channel in a specific slot after an idle slot $\tau_{i,w}$ and after a busy slot $\tau_{b,w}$ for the class w will be:

$$\tau_{i,w} = \frac{\sum_{j=0}^{m_w} b_{0,j,0,w}}{P_i} \quad \text{and} \quad \tau_{b,w} = \frac{\sum_{j=0}^{m_w} b_{1,j,0,w}}{1-P_i} \tag{1}$$

A different approach to $p_{0,w}$ and $p_{1,w}$ probabilities is proposed. Firstly, a correlation measure between the $AIFS[w]$ is introduced. $r(w_1, w_2)$ is defined as:

$$r(w_1,w_2) = \max\left[1 - \frac{AIFS[w_1] - AIFS[w_2]}{E[\Psi]}, 0\right],\ w_1 \geq w_2 \tag{2}$$

Where $AIFS[w]$ equals 2, 2, 3 and 7 for AC3, AC2, AC1 and AC0 respectively, w_1 and w_2 correspond to two different ACs under comparison and $E[\Psi]$ is the average consecutive idle slots given in equation 3.

Table 1 EDCF values for parameters $CW_{\min}$, $CW_{\max}$, m_w and $AIFS[w]$ of the four Access Classes.

$$E[\Psi] = \frac{1}{1-P_i} - 1 \tag{3}$$

This correlation measure is an indicative percentage of the access attempts of w_2 AC that can interfere with a higher priority class w_1.

Given the fact that there exist N_w demands from each AC in the common channel, the collision and idle probabilities can be defined as function of transmitting probabilities:

$$p_{0,w} = 1-(1-\tau_{i,w})^{N_w-1} \prod_{z<w} (1-\tau_{i,z})^{\lfloor N_z \cdot r(w,z) \rfloor} \prod_{z>w} (1-\tau_{i,z})^{N_z} \tag{4}$$

$$p_{1,w} = 1-(1-\tau_{b,w})^{N_w-1} \prod_{z>w} (1-\tau_{b,z})^{N_z} \tag{5}$$

$$q_0 = \prod_{w=0}^{3} (1-\tau_{i,w})^{N_w} \tag{6}$$

$$q_1 = \prod_{w=0}^{3} (1-\tau_{b,w})^{N_w} \tag{7}$$

The above system of equations with variables $\tau_{i,w}$, $\tau_{b,w}$, $p_{0,w}$, $p_{1,w}$, q_0 and q_1 can be easily solved by means of the fixed point iteration method and using a percentage of memory in every iteration. The probability of successful transmission for every AC will be:

$$P_{s,w} = P_i \cdot N_w \cdot \tau_{i,w} \cdot \prod_{z<w} (1-\tau_{i,z})^{\lfloor N_z \cdot r(w,z) \rfloor} \cdot (1-\tau_{i,w})^{N_w-1} \cdot \prod_{z>w} (1 -$$
$$+ (1-P_i) \cdot N_w \cdot \tau_{b,w} \cdot (1-\tau_{b,w})^{N_w-1} \cdot \prod_{z>w} (1-\tau_{b,z})^{N_z}$$

And the collision probability is:

$$P_c = 1 - P_i - \sum_{w=0}^{3} P_{s,w} \tag{8}$$

Finally the saturation throughput for every AC S_w is given:

$$S_w = \frac{P_{s,w} E[P]}{P_i \cdot slot + \sum_{w=0}^{3} P_{s,w} T_{s,w} + P_c T_c} \tag{9}$$

Where, $E[P]$ is the average payload length, $slot$ is the slot duration, $T_{s,w}$ is the transmission duration for class w and T_c is the average collision duration. These values can be found by using [1] and the table I.

IV. RESULTS

The proposed analysis is compared to the analysis of [4] and [5] and found to be a better approximation of simulations made in the OPNET^{TM} simulator. Analysis of [4] has been modified by replacing equation 11 by:

$$S_i = \frac{p_{s,i} E[L]}{(1-p_b) \cdot \delta + \sum_{i=0}^{3} p_{s,i} T_{s,i} + \left[p_b - \sum_{i=0}^{3} p_{s,i}\right] T_{c,i}} \tag{10}$$

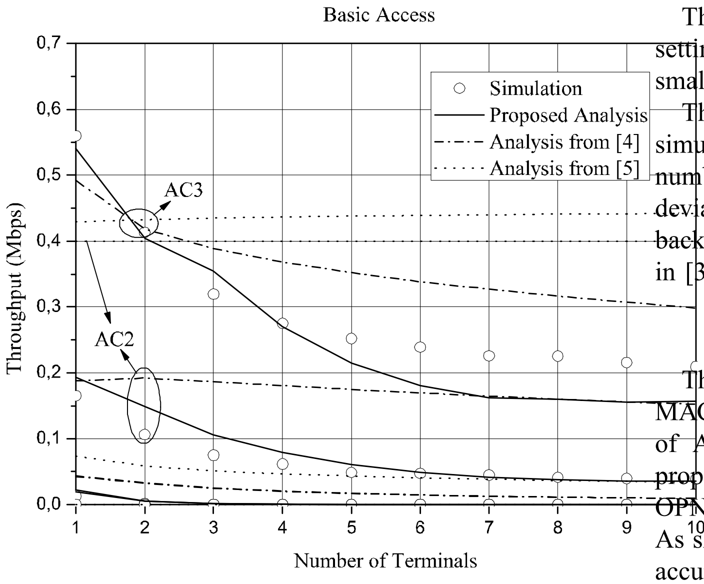

Fig. 1. Saturation Throughput of all four EDCF access classes for 1Mbps channel rate and basic access. Comparison between the proposed analysis, Opnet simulation and the modified analysis of [4] and [5] for the settings of table I.

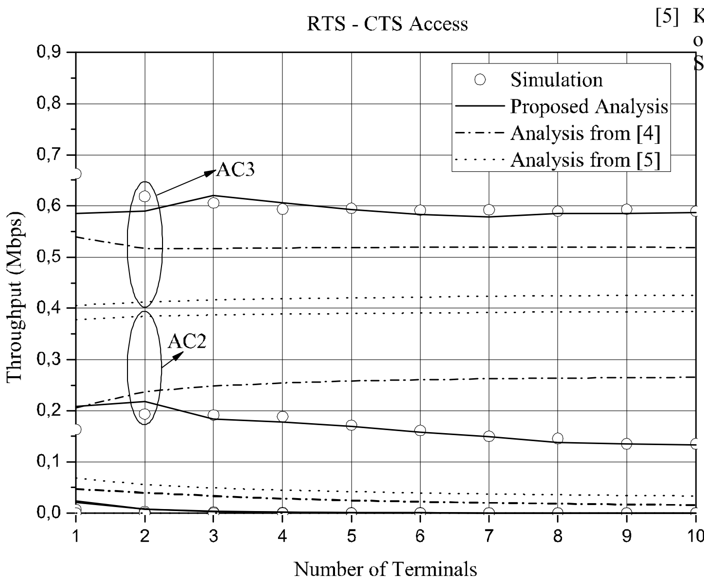

Fig. 2. Saturation Throughput of all four EDCF access classes for 1Mbps channel rate and RTS-CTS access. Comparison between the proposed analysis, Opnet simulation and the modified analysis of [4] and [5] for the settings of table I.

This modification has been proposed in [2] as well. Moreover, the results for RTS-CTS without the modification are unrealistic.

The analysis of [5] provides unrealistic results for the settings used in the simulation. The throughput seems to have small dependency of the number of terminals as in [5].

The proposed analysis is proved to be very close to the simulations with the exception of AC3 class in case of large number of terminals and basic access. In this case a large deviation arises. This can be explained as a weakness of the backoff analysis. The same problem can be somewhat found in [3].

V. Conclusion

The saturation throughput analysis is applied on 802.11e MAC protocol. Some alterations that incorportae the effect of Arbirtrary Interframe Spacing (AIFS) effect have been proposed. The results of the analysis are compared with OPNET simulations and previous works from the references. As shown in the results, the proposed analysis is greatly more accurate owing to the proposed alterations.

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