PERFORMANCE ENHANCEMENT OF WLAN IEEE 802.11 FOR ASYMMETRIC TRAFFIC

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Abstract- **Most studies about the performance of IEEE 802.11 consider scenarios of ad-hoc topology and networks where all stations have the same traffic load (symmetric traffic conditions). This paper presents a study of performance parameters of more realistic networks. We focus the attention on WLAN with infrastructure networks, where the traffic distribution is asymmetric. In this case, the traffic load at the Access Point is much heavier than that at user stations. These studies are more realistic because most nowadays installed WLAN are infrastructure topology type, due to the fact that they are used as access networks. In this case, the Access Point has to retransmit all incoming traffic to the Basic Service Set and therefore its traffic load is higher. Finally, the paper presents the tuning of the Contention Window, taken from IEEE 802.11e, used to increase the system performance under asymmetric traffic conditions, and the proposal of an adaptive algorithm to adapt the MAC layer settings to the system traffic load.**

Index Terms—**Asymmetric, IEEE 802.11, WLAN.**

I. Introduction

Since 1997, when the Institute of Electrical and Electronics Engineers (IEEE) defined the first standard IEEE 802.11 for wireless local area networks it has evolved a lot. The former IEEE 802.11 worked at 2.4 GHz and at data rates of 1 and 2 Mbps. Later it appeared IEEE 802.11b that using the same frequency got 11 Mbps. IEEE 802.11a was developed next, this one changed its working frequency to 5 GHz reaching 54 Mbps, but the change of frequency represented a drawback on interoperability with older equipment. In this way, the IEEE 802.11g was developed, reaching 54 Mbps, but working again at 2.4 GHz. Finally, in September 2003 a new working group has begun to work in order to develop IEEE 802.11n that should get 100 Mbps. All these standards' working procedures are practically the same, and only change the modulation, some fields of the physical layer and the duration of the slot and the inter-frame space access times (DIFS, SIFS, PIFS).

Among the other several IEEE 802.11 standards we should note that IEEE 802.11e defines procedures to manage network Quality of Service using classes of service.

Up to now, several papers have been written on different aspects of IEEE 802.11. Reference [1] studies the throughput of the network considering radio coverage aspects and the hidden terminal problem. References [2] and [3] show simulation and mathematical results of the throughput of a IEEE 802.11 single cell WLAN, and also propose dynamic adjustments of the backoff algorithm to improve the whole performance. In [4] and [5] we can find several analysis on propagation issues. All these analysis are based on system traffic saturation, and calculate the saturation throughput. More recently, several papers have appeared that work without this premise and consider situations of no congestion [6], [7]. Finally, the proposals of the working group IEEE 802.11e, that gives Quality of Service (QoS) possibilities to wireless LANs, have also been studied in [8].

An aspect to have in mind is that most WLANs are used as the access network of a set of computers to the local intranet or towards global Internet, and in few occasions, the traffic is between two components of the same Basic Service Set (BSS), as can be observed in Fig. 1.

When using infrastructure networks, the Access Point (AP) acts as a bridge of the BSS to the wired LAN, and it has as well to transmit all incoming traffic to the BSS. Moreover, when the communication is between two computers of the same BSS, user information also goes through the AP who acts as a repeater.

All the previous cited papers study IEEE 802.11 performance considering a symmetric traffic distribution between all computers of the BSS, and we can observe that this hypothesis differ from the majority of installed WLANs.

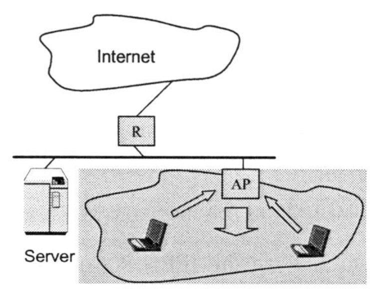

Figure 1. Infrastructure WLAN with asymmetric traffic

Having these considerations in mind, in [9] we have evaluated the IEEE 802.11 network performance under conditions of asymmetric traffic, and we presented several enhancement proposals based on the tuning of the contention window and the inter-frame space access times.

Going a step further, the focus of this paper is to propose an adaptive algorithm in order to adapt the MAC layer settings to the system traffic load. In this way, we center our study in the WLAN performance, considering IEEE 802.11 networks that are in a situation of asymmetric traffic, where the traffic load at the AP is much heavier than that at user stations (US).

Having these considerations in mind, this paper is distributed as follows: section II presents the main topics of the IEEE 802.11 MAC working procedure, section III describes the simulation environment, section IV presents the adaptive algorithm proposal to adapt the MAC layer settings to the system traffic load, section V evaluates the system performance employing the algorithm presented and exposes the main results obtained in presence of asymmetric traffic, and finally, section VI concludes with the most relevant points of the article.

II. IEEE 802.11 MAC PROTOCOL

IEEE 802.11 has two operating modes: Distributed Coordination Function (DCF) and Point Coordination Function (PCF). The most common working mode is DCF that uses the medium access control (MAC) algorithm named CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance), it works as follows. Before initiating a transmission, a station senses the channel to determine whether it is busy. If the medium is sensed idle during a period of time named distributed interframe space (DIFS), the station is allowed to transmit. If the medium is sensed busy, the transmission is delayed until the channel is idle again. A slotted binary exponential backoff interval is uniformly chosen in [0, CW-1], where CW is the contention window. The backoff timer is decreased as long as the channel is sensed idle, stopped when a transmission is in progress, and reactivated when the channel is sensed idle again for more than DIFS. When the backoff timer expires, the station attempts for transmission. After each data frame successfully received, the receiver transmits an acknowledgement frame (ACK) after a short interframe space (SIFS) period. The value of CW is set to 32 in the first transmission attempt, and ascends integer powers of 2 at each retransmission, up to a pre-determined value (usually 1024).

III. SIMULATION ENVIRONMENT DESCRIPTION

In order to analyze the IEEE 802.11 performance, we use a simulation tool implemented at the Technical University of Catalonia (UPC). Our simulation program, written in C++ programming language, follows all the IEEE 802.11 protocol details. It permits the evaluation of different parameters: throughput (user data correctly transmitted by users without considering retransmissions and headers), average transmission delay, average queue delay, time fraction during which all network stations are in backoff state, probability of collision. The simulation tool has been verified comparing the results obtained with the information published in [2], under identical simulation conditions.

The standard IEEE 802.11g has been chosen to realize this study. Simulation environment consists in one BSS composed of 1 AP and 10 US. The stations transmit data packets with constant payload size of 1023 bytes, and the time between consecutive arrivals follows an exponential distribution function. All US are under coverage area. Hidden terminal situation and transmission errors are not considered. We consider the AP transmitting the same amount of traffic than the 10 US altogether. Taking an example, this means that for a global normalized offered load of 0.6, the AP offers 0.3 and user stations offer 0.03 each one.

The initial contention window values for AP and US are CW_{min}=32 and CW_{max}=1024. The values of the remaining parameters used to obtain the numerical results are exposed in Table I.

IV. ENHANCEMENT PROPOSALS

An interesting parameter to analyse is the queue delay, defined as the time that a packet ready to be transmitted is delayed until it becomes the first in its transmission queue.

TABLE I

MAIN PARAMETERS USED IN THE SIMULATIONS

	802.11g (802.11b compatible)	802.11g (ERP-OFDM)
Transmission data rate (Mbps)	1, 2, 5.5, 11	6, 9, 12, 18, 24, 36, 48, 54
MAC header	34 bytes	
ACK	14 bytes	
Propagation time	1 μs	
Long PHY Preamble	144 μs	16 μs
Short PHY Preamble	72 μs	
Long PHY Header	48 μs	4 μs
Short PHY Header	24 μs	
Slot Time	20 μs	
SIFS	10 μs	
DIFS	50 μs	
PIFS	30 μs	

Obviously, the AP average queue time is higher than the obtained by the US, since the AP is more loaded than any other station in the system.

An important objective to achieve is the reduction of the AP queue delay. This parameter can become especially critical, when the network is managing traffic with strict real time requirements. Under this kind of situation it is important to assure end to end delays, and, in this way, to control the delays that can be generated at any step of the communication.

In order to reduce this AP queue delay, we have studied several proposals that have been published in [9]. Conclusions were that the mechanisms that allow better performance are those based on the tuning of the contention window, through the management of its minimum value (CW_{min}) and its priority factor (the growing factor of the contention window value *PF*).

Thereby, in this paper, we present an adaptive algorithm proposal to adapt the MAC layer settings to the system traffic load, based on the tuning of the contention window parameters.

This algorithm is based on the number of packets remaining in the stations queues, when a new data packet is inserted in them.

We have implemented two different versions of the algorithm.

The first one works as follows. Denote the number of packets remaining in the AP queue as N_{QAP}, and the average number of the packets remaining in the US queues as N_{QUS_m} (this value is computed taking into account the 10 last packets transmitted by all the US). When a new data packet is generated at the AP and it is introduced in the corresponding transmission queue, the AP verifies if $N_{QAP} > \alpha \cdot N_{QUS\_m}$. If this condition is true, the AP changes its minimum and maximum contention window value to $CW_{min} = 8$ and $CW_{max} = 32$. Finally when a new data packet is generated at any of the US and it is introduced in the corresponding transmission queue, the US verifies if $N_{QAP} > \beta \cdot N_{QUS\_m}$. If this condition is true, the US increases its priority factor to $PF_{US}=6$.

On the other hand, the second algorithm proposed works as follows. For each new data packet generated at the AP and introduced in the transmission queue, the AP verifies if $N_{QAP} \geq N_{AP}$, where N_{AP} corresponds to a fixed threshold of packets. If this condition is true, the AP changes its contention window values to $CW_{min} = 8$ and $CW_{max} = 32$. Finally, for each US data packet introduced in the transmission queue, the US checks if $N_{QUS} \leq N_{US}$, where N_{QUS} corresponds to the number of packets remaining in the US queue, and N_{US} stays for a fixed threshold of packets. If this condition is true, the US increases its priority factor to $PF_{US}=6$.

Both algorithms working procedures are basically the same. The main difference is that using the first one, an additional information exchange between AP and US has to be performed, whereas employing the second proposal no extra messages interchange is needed.

V. SYSTEM BEHAVIOR

In order to evaluate the adaptive algorithm proposed, we present the IEEE 802.11g system performance for different transmission data rates. As we are evaluating its behavior for asymmetric traffic, we present results for non-saturation conditions. Furthermore, we compare its performance for different values of α, β, N_{AP} and N_{US}, with the results obtained employing non-adaptive priorizing methods at the AP.

The different alternatives employed in order to priorize the AP channel access are following:

a) non-adaptive AP contention window values reduction to $CW_{min} = 8$ and $CW_{max} = 32$
b) Combination of method a) with the use of an AP priority factor of $PF_{AP}=2$ and an US $PF_{SU}=6$ (non-adaptive)
c) Adaptive algorithm 1 with $\alpha=0.5$ (without changing PF_{SU} value)
d) Adaptive algorithm 1 with $\alpha=1.5$ (without changing PF_{SU} value)
e) Adaptive algorithm 1 with $\alpha=0.5$ and $\beta=0.5$
f) Adaptive algorithm 2 with $N_{AP}=1$ and $N_{US}=0$

Fig. 2 and 3 present the average AP queue delay for different data rates (1 and 18 Mbps), offered load conditions, and different AP priorizing mechanisms. As can be observed, the alternatives c) – f), employing the adaptive algorithm, achieve an important decrease in the average AP queue delay with regard to the original case, without AP priorization. Furthermore, the differences between the various alternatives using the adaptive algorithm are small, due to the fact that user stations are less loaded and most of the times have their transmission queue empty, and consequently N_{QUS_m} and N_{QUS} are closer to zero.

Moreover, employing any of the adaptive proposals, a worse AP queue delay performance is obtained, in comparison with the non-adaptive alternatives a) and b). On the other hand, the employment of the adaptive proposals deals with a better US performance with regard to the non-adaptive alternatives.

Fig. 4 and 5 present the AP average transmission delay for 1 and 18 Mbps. This delay is defined as the interval of time starting at the instant that a packet is ready to be transmitted (it is the first one in its transmission queue) and finishes when the ACK packet is received. The alternatives proposed are based in the tuning of the contention window. In this way, when the AP channel access is priorized, not only the AP average queue delay is decreased, its transmission delay becomes significantly lower as well.

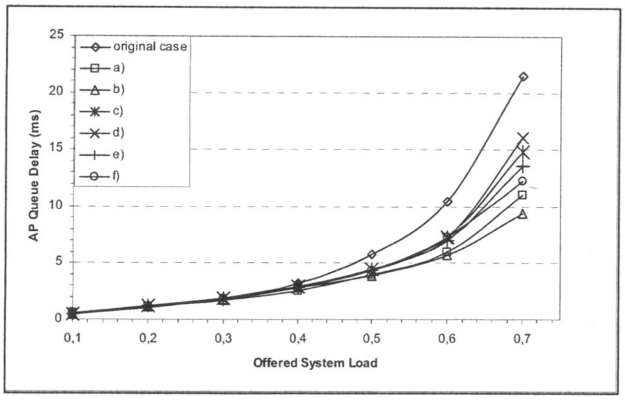

Figure 2. AP queue delay vs. offered system load for 1 Mbps, and different priorization alternatives

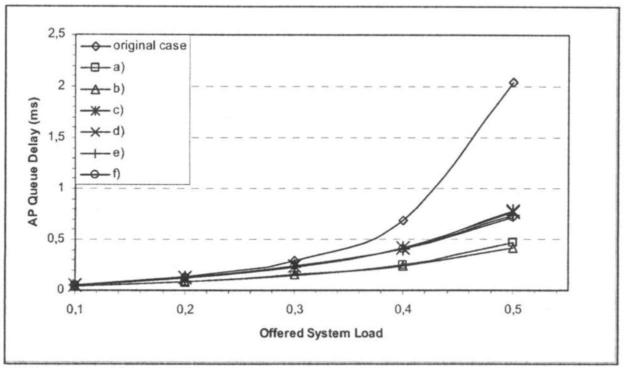

Figure 3. AP queue delay vs. offered system load for 18 Mbps, and different priorization alternatives

Subsequently, Fig. 6 and 7 present the density of AP transmitted packets in function of different AP queue time intervals, and for different transmission rates (1 and 18 Mbps). In the figures presented, we can observe that this density is higher at lower intervals (what means that packet delay is lower), if any of the AP priorizing alternatives are employed. Moreover, when employing the adaptive alternatives c) - f), this density is less than the obtained using the non-adaptive algorithms a) and b) at lower intervals. In this way, when using any of the adaptive alternatives the MAC layer settings are adapted to the system traffic load, and consequently, a higher variation in the density of AP transmitted packets can be observed.

Finally, Fig. 8 and 9 present the density of AP transmitted packets as a function of the number of packets remaining in the AP queue, when they are inserted in it. This study has been performed for different transmission rates (1 and 18 Mbps). The performance obtained in this case agrees with the exposed in previous paragraph. This density is higher for a lower number of packets remaining in the AP queue, if any of the AP priorizing alternatives are employed. Moreover, it is higher when employing the non-adaptive alternatives a) and b), because of the use of the adaptive alternatives deals with a higher variation in the density of AP transmitted packets.

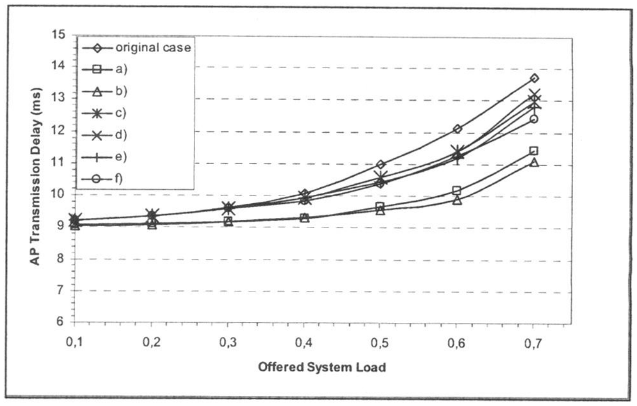

Figure 4. AP transmission delay vs. offered system load for 1 Mbps, and different priorization alternatives

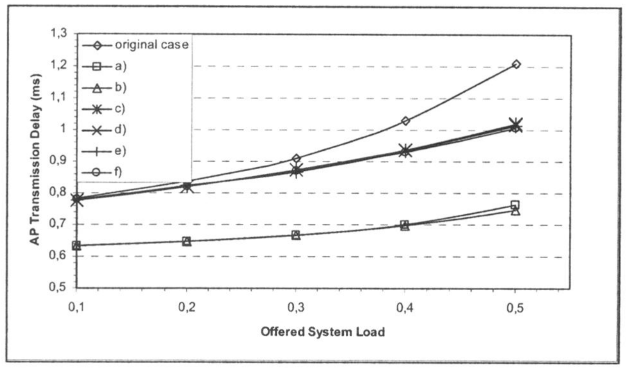

Figure 5. AP transmission delay vs. offered system load for 18 Mbps, and different priorization alternatives

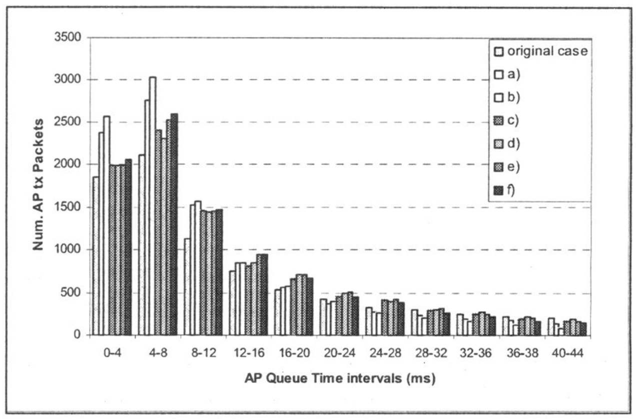

Figure 6. Density of AP transmitted packets vs. AP queue time intervals, for 1 Mbps, offered system load of 0.7 and different priorization alternatives

VI. Conclusions

Most studies about the performance of IEEE 802.11 networks consider scenarios of ad-hoc topology and networks where all stations have the same traffic load (symmetric traffic conditions). This paper studies the behavior of IEEE 802.11 WLAN under conditions of asymmetric traffic, which is the more common case of WLAN used as access networks.

An important objective is to achieve the reduction of the AP queue delay. The performance of this parameter is especially critical when the network is managing traffic with strict real time requirements. When networks are working under this situation, it is important to control the delays that can be generated at any step of the communication.

Thereby, in this paper, we present an adaptive algorithm proposal to adapt the MAC layer settings to the system traffic load, based on the tuning of the contention window parameters.

The results exposed show that the adaptive alternatives presented achieve an important decrease in the average AP queue delay and transmission delay with regard to the original case, without any AP priorization.

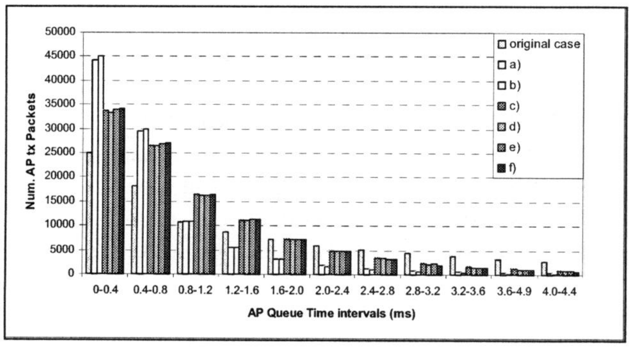

Figure 7. Density of AP transmitted packets vs. AP queue time intervals, for 18 Mbps, offered system load of 0.5 and different priorization alternatives

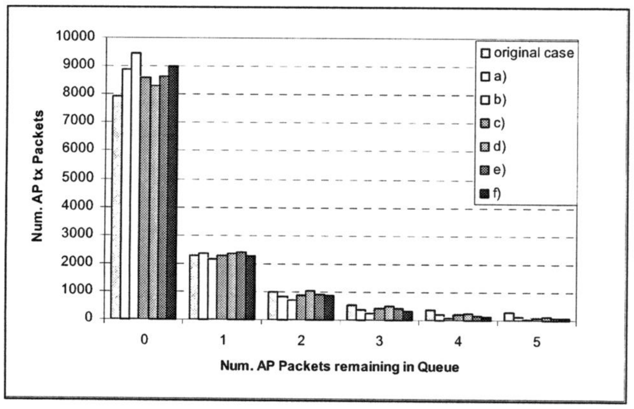

Figure 8. Density of AP transmitted packets vs. number of AP packets remaining in queue, for 1 Mbps, offered system load of 0.7 and different priorization alternatives

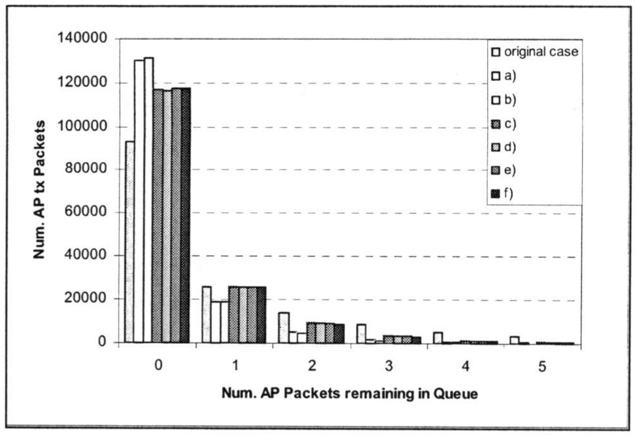

Figure 9. Density of AP transmitted packets vs. number of AP packets remaining in queue, for 18 Mbps, offered system load of 0.5 and different priorization alternatives

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