WLAN Throughput Improvement via Distributed Queuing MAC

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***Abstract*— This paper analyzes the performance of a MAC scheme for wireless local area networks (WLANs) that makes use of distributed queues to improve radio channel utilization. Analytical values for the maximum throughput performance are derived as a function of the system parameters. The obtained results show that the proposed scheme outperforms the legacy 802.11 MAC protocol in terms of maximum stable throughput. This benefit is obtained from eliminating back-off periods and collisions in data packet transmissions while minimizing the needed control overhead. The proposal also makes performance to be independent of the number of nodes transmitting in the system and provides stability for high load conditions.**

***Index Terms*— Distributed queuing, expected effective throughput, IEEE 802.11, MAC, WLAN.**

I. Introduction

A GREAT variety of Medium Access Control (MAC) schemes have been developed and studied for wireless communication systems in recent years. All these proposals pursue the objective of efficiently managing the scarce radio frequency spectrum resource.

Focusing on the possibility of getting a certain throughput improvement in a WLAN environment, the system performance of the standard 802.11 MAC mechanism has been analyzed. It is clear that, for the DCF mode, the throughput is remarkably degraded due to the presence of collisions and back-off periods. Therefore, the elimination of such wasted intervals should produce a throughput improvement. On the other hand, PCF mode is a polling mechanism with very low efficiency for a variable number of transmissions and bursty traffic sources.

With these ideas in mind, a MAC scheme based on distributed queues [1]-[2] is proposed in order to improve radio channel utilization in WLAN environments. The proposed scheme, called Distributed Queuing Collision Avoidance (DQCA) is a distributed always-stable high performance protocol that behaves as a random access mechanism for low traffic load and switches smoothly and automatically to a reservation scheme when traffic load grows. The key feature of the proposed scheme is that it eliminates the collisions and back-off periods in data packet transmissions. Moreover, its structure based on queues is specially fitted to introduce scheduling mechanisms which may provide QoS features. In order to get a measure of the potential obtainable benefit of using this proposal, analytical results on maximum throughput figures have been obtained in a representative scenario.

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II. Throughput Bounds for DQCA MAC in WLANs

In this section we will briefly describe the MAC proposal, which is able to work over any 802.11x PHY layer. Then the value of the performance bound that can be achieved using it in a wireless communications system will be derived. The main objective is to evaluate the benefits that could be obtained from using this mechanism in a WLAN environment.

A. DQCA Overview

DQCA is based on a MAC scheme presented in [1] for a CDMA environment. The proposed idea is to apply the same mechanism of the MAC called DQRAP/CDMA (see [1]) in the case that only one spreading code is available (TDMA-like operation similar as in [2]), which corresponds to a WLAN environment situation. Due to space constraints, only an overview of the characteristics of the MAC is presented here. The objective is to assess the benefits that can be obtained from applying this MAC in WLAN, which is a different environment from the one that was initially defined for. DQCA is a distributed always-stable high-performance protocol that has the following main features:

- It eliminates back-off periods and collisions in data packet transmissions.
- Its performance is independent of the number of nodes transmitting in the system.
- It is stable for whichever the traffic conditions are.
- It uses very few bits for operation purposes (control plane) in comparison with any other centralized or distributed MAC.

Fig. 1 shows the frame structure of the novel MAC proposal, suitable for an evolved 802.11 WLAN. The successful transmission of a data packet involves one whole frame. The frame duration includes five time intervals, that are:

- A contention window, with fixed length T_{access}, divided into m contention periods.
- A data transmission interval, where data packets are sent from nodes. The duration of this period is called T_m and could be variable.
- A SIFS interval (Short Inter Frame Space), for processing purposes.
- A control window, where ACK and CTS information are broadcast by a coordinating node. ACK information is the normal acknowledgement information referring to data transmission, whereas CTS information contains the detection state of the previous m contention periods of the contention

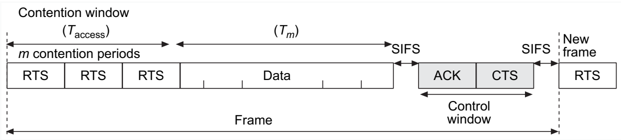

Fig. 1. Frame structure of DQCA.

window. This state should be, for each period, one out of three possibilities: empty, success or collision. Thus, only a very few bits are needed for this control packet.

•Another SIFS interval before the beginning of the next frame in order to process the MAC rules (see below).

This MAC protocol is based on two distributed queues: one of them devoted to the data packet transmission scheduling, and the other devoted to the collision resolution algorithm. These two queues are simply represented by four integer numbers, recorded at every node (i.e. distributed queues), which represent the number of nodes and the position of every node in each queue. Every node has to maintain and update these numbers each frame based on the feedback information broadcast by a coordinating node through some control packets. Any node in the network could perform this coordinating role, so enabling peer-to-peer communications if all the nodes are in the transmission range of the others. Then every node applies three sets of rules to update the queues, which allow them to know precisely the number of nodes and their position in each queue, without any estimation concerning the total number of nodes (active or not). With this procedure, a collision-free data transmission is achieved. The basic idea of the MAC protocol is to concentrate node access requests (and then collisions) in the contention window while data transmission is kept collision-free without using expensive (in terms of load) explicit control packets to coordinate transmissions.

To outline the protocol operation, consider a node that has just arrived to the system and has data to transmit. It must check the state of both the distributed queues in order to decide whether it is enabled to attempt a system access request or a data transmission. Nodes will be forbidden from attempting accesses if there are collisions pending to be resolved. This is a key feature of the protocol as it avoids unstable situations. If the node is enabled to access, it will randomly select one of the control slots of the control subframe and it will transmit an access request (RTS) at this control slot. The node will enter one of the queues (named Collision Resolution Queue) if its access request has collided. This queue will manage the collision resolution. Then, if the access request is successful or the collision has been resolved it will get a position in the second queue (named Transmission Queue) and perform a collision-free data transmission using the queue order. Due to space constraints, the reader is referred to [1] and [2] for the rest of the details on the MAC protocol operation.

B. Throughput Bounds for DQCA

As derived from [1]-[2], DQCA is able to achieve a maximum stable relative channel usage up to the channel capacity when $m > 2$ only deducting the time intervals devoted to transmit control information. Then, as we are considering a particular case we can derive that this condition will still be fulfilled. Therefore, we can evaluate the relative throughput (channel net usage) from the average transmission time of a data packet (T_m) and the total duration of a frame (T_v) as:

$$\rho = \frac{T_m}{T_v}$$

The duration of a frame can be expressed as:

$$T_v = T_s + T_{access} + T_{feedback}$$

where T_s is the time the channel is busy for a successful transmission, T_{access} is the duration of the contention window and $T_{feedback}$ is the time devoted to control information transmission. The value for T_s can be calculated as:

$$T_s\text{=Physical\_Header+MAC\_Header+}T_m\text{+}t_p$$

where Physical_Header represents the synchronization period (PHY level), MAC_header is the time needed to transmit the MAC header bytes and t_p is the channel propagation delay. The value for T_{access} is:

$$T_{access}\text{=m(Physical\_Header+RTS)}$$

where RTS stands for the period of time needed to transmit the access request represented by the special RTS packets. It is not necessary to take into account the propagation delay as the data transmission is allowed to start without waiting for access request processing [1]. Finally, $T_{feedback}$ can be evaluated as:

$$T_{feedback}\text{=2*SIFS+2* Physical\_Header +CW+}t_p$$

where CW stands for the duration of the control window transmission (ACK+CTS information). In these conditions, the resulting throughput value ρ is:

$$\rho = \frac{T_m}{(3+m)Phy_H + MAC_H + T_m + 2t_p + mRTS + 2SIFS + CW} \quad (1)$$

Note that RTS access request packets could be minimized in duration as the PHY level only needs to detect three different states (empty, success, collision) but no information bits have to be carried through [2]. CTS feedback information could also be reduced to only six bytes, which contain information enough for the nodes to execute the MAC protocol algorithm. Thus, control information is minimized and net throughput maximized.

III. Throughput Comparison

In order to validate the proposed approach and to get a figure of the obtainable gain, the two DFC operation modes of the 802.11 MAC have been selected as reference values. Even DQCA uses a coordinating node, it works in a distributed manner because the coordinating node only acts as a detector of the access requests/acknowledgments and it behaves simply as a repeater in order to broadcast this information to the rest

TABLE I
SCENARIO PARAMETER VALUES

aSlotTime	20μs	MAC$_H$	34 bytes
SIFS	10μs	Payload	0-2312 bytes
DIFS	50μs	ACK	14 bytes
t$_p$	1μs	RTS	20 bytes
Wmin	31	CTS	14 bytes
Wmax	1023		
Phy$_H$	96μs		

TABLE II
CHANNEL MODEL SETTINGS

Channel State	Probability	SNR (uniform)
GOOD	0.80	[10-20] dB
BAD	0.20	[0-10] dB

of the nodes. Furthermore, any node could perform this role, so no access point or centralized infrastructure is needed. Reservation centralized schemes (as PCF) have also been discarded as a reference because they always need more control traffic load than DQCA to operate, so their performance will always be poorer.

To get example figures, a scenario with N always-active nodes has been selected. The reference scenario is defined by a set of parameters provided in Table 1. The SNR model for the wireless channel variation is a two-state discrete Markov chain as in [5]. With this model, the channel can be in two possible states, good and bad, and within each state, a uniform random variable determines the SNR value for the transmissions. Table 2 shows the model settings used. Consequently, a set of SNR thresholds should be defined in order to select the appropriate data rate for PHY transmissions. These thresholds have been selected based on the results presented in [6] and are shown in Table 3. An ideal SNR detection and perfect rate selection scheme is supposed to exist for the 802.11 MAC operation (ideal link adaptation).

TABLE III
DATA RATE THRESHOLDS

Rate	1 Mb/s	2 Mb/s	5.5 Mb/s	11 Mb/s
SNR	$<$ 4 dB	4-7.5 dB	7.5-11 dB	$>$ 11 dB

Regarding the MAC parameters, the following considerations have been made:

•Duration of RTS access requests transmissions is reduced to only 2 μs as no data information is needed to be carried through.

•CW information uses only 13 bytes.

Fig. 2 shows the comparison between the obtained average throughput using the two different DCF of the 802.11b MAC and the proposed scheme, with m=3, versus the packet length, for N=2 and N=20 nodes. Note that the curve for DQCA throughput is independent of the number of nodes. This curve has been obtained analytically by means of expression (1) weighting all the values according to the channel state model steady-state probabilities, while the reference values for WLAN have been obtained from the expressions in [4].

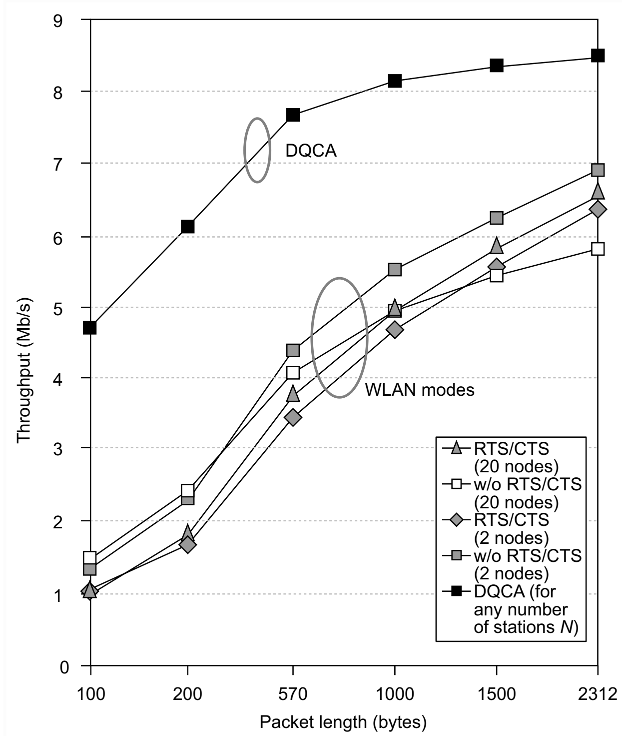

Fig. 2. Achievable estimated throughput improvement.

All values have been obtained assuming the transmitter buffers always have packets to send (saturation).

We can observe that results obtained using DQCA improve significantly the system capacity over 802.11 MAC. Furthermore, it is worth noting that DQCA is able to maintain throughput values for any number of nodes N in the system. Observe that the system efficiency is improved when packets grow in bit size, as the control part of the frame becomes smaller with respect to the total frame duration.

IV. CONCLUSION

A MAC proposal named DQCA suitable for WLAN systems has been presented and its performance has been analyzed. Using DQCA represents a throughput improvement when compared to the legacy 802.11 MAC protocol. Under the studied scenario, a minimum of a 25% throughput improvement in terms of effective data rate can be obtained.

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