

Opportunistic Scheduling for WLAN systems using Cross-Layer Techniques and a Distributed MAC

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Abstract— This paper proposes a novel Cross-Layer optimization mechanism for WLAN systems and analyses its performance in terms of throughput and mean packet delay. The proposed scheme makes use of a MAC-PHY interaction and a near-optimum distributed MAC to improve radio channel utilisation. The proposed technique allows the MAC layer to improve the system efficiency by means of certain PHY information knowledge. Simulation results show that the obtained benefits are quite remarkable so the proposed scheme is feasible to be introduced in future wireless communication systems.

Keywords: *Cross-Layer, DQCA, Opportunistic Scheduling, MAC.*

I. INTRODUCTION

During the last decade, a significant growth of digital wireless communications systems has been noted. The research discipline of wireless communications is one of the areas that are currently undergoing major progress and developments. Wireless networks have the traditional OSI layer-based architecture from wired networks, where each layer is worked out based on its parameters as a separate entity. Even though this consideration simplifies protocols' design and treatment, it seems to be suboptimal for wireless communication systems. At least, this is due to the fact that the wireless medium is available to multiple users that try to get access and transmit their information, and this medium is different and independent for each user.

Although a variety of Medium Access Control (MAC) schemes have been designed for wireless systems [1]-[4] in order to manage the radio frequency spectrum resource and to provide certain Quality of Service (QoS) requirements to mobile users, the efficiency of such systems can be optimised when considering some vertical coupling between layers. In this case, MAC protocols, radio link control, Radio Resource Management schemes and routing algorithms can benefit from some degree of awareness of the time varying characteristics of the radio channel. Therefore, physical layer (PHY) parameters should become available to higher layers. Based on this information, higher protocol layers can adapt their behavior in order to improve network performance. This general concept is known as Cross-Layer Optimization [5],[6].

As far as 802.11b based systems are considered, nodes may transmit their packets using one of the four available rates depending on the channel state (attenuation or signal-to-noise ratio), while the Distributed Coordination Function (DCF) and Point Coordination Function (PCF) modes are used in the MAC layer to manage requests to access. It is well known [8] that the DCF mode's throughput is significantly degraded due to the presence of collisions and back-off periods. Therefore, the elimination of such wasted intervals should improve WLANs' throughput. On the other hand, PCF mode is a polling mechanism with very low efficiency for a variable number of transmissions and bursty traffic sources [9].

The Distributed Queuing Collision Avoidance (DQCA) [10] is a high performance protocol that eliminates the collisions and back-off periods in data packet transmissions for WLAN systems. Furthermore, DQCA is suitable to include cross-layer mechanisms which aim to provide better utilization of the radio resources by means of certain MAC-PHY interaction.

This paper deals with WLAN systems based on the 802.11b standard [7]. An infrastructure mode is considered where a number of nodes contend for the channel access and transmit their packets to an Access Point (AP). Hence, the study is restricted to the uplink

The aim of this paper is to present an opportunistic scheduling for 802.11b WLAN systems using a cross-layer technique and the DQCA MAC protocol. In the proposed algorithms higher priority is given to nodes with higher measured Signal to Noise Ratio. Furthermore, the relative waiting time in the accessing system is also taken into account in data transmission scheduling. The benefits of such Cross-Layer interactions are analyzed by computer simulations and are presented in terms of throughput and mean packet delay.

The structure of the paper is as follows: Section II gives a brief description of the DQCA MAC protocol. Section III is devoted to the description of the proposed cross-layer technique. Section IV addresses the simulation scenario. In Section V, simulation results are presented and finally, in Section VI some conclusions are done.

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II. DQCA DESCRIPTION

DQCA is a distributed high-performance protocol that behaves as a random access mechanism under low traffic conditions switching smoothly and automatically to a reservation scheme when traffic load goes up.

The mentioned protocol has the following features:

- Eliminates back-off periods and collisions in data packet transmissions.
- Performs independently of the number of stations transmitting in the system.
- Keeps maximum achievable throughput even if the offered load temporarily exceeds the maximum capacity.
- It inherently includes a Cross-Layer dialogue that properly manages packet data transmissions.

The main goal of the DQCA protocol is to offer node accesses in a reserved time interval, confining collisions only to this part of the frame. In order to achieve this, a Contention Window divided up into some short time intervals is reserved for access requests in each time frame, where special Request to Send (RTS) packets are sent by transmitting nodes. The rest of the frame time is assigned to collision-free data transmission. Furthermore, time slots for acknowledgment (ACK) and feedback information (Clear to Send, CTS) packets in the downlink are also reserved.

DQCA is based on two distributed queues, the Data Transmission Queue (DTQ), and the Collision Resolution Queue (CRQ). The first one is related to data packet transmission scheduling, while the second one is devoted to the collision resolution algorithm. These queues are represented in each node by four integer numbers, denoted by TQ, RQ, pTQ and pRQ.

TQ is the number of messages waiting for transmission in the DTQ, while RQ is the number of collisions waiting for resolution in the CRQ. Likewise, pTQ is the node position within the DTQ and pRQ is the node position within the CRQ. It is worth noting that TQ and RQ should have the same values for all nodes (i.e. they represent distributed queues), whereas pTQ and pRQ represent the positions within the queues of each node, and then they may be different for each node. Each node has to update these numbers in every time frame based on feedback information broadcasted by the Access Point in a downlink packet.

A new node in the system that has data to transmit should check the state of both the distributed queues in order to send an access request or to transmit data. If a node is enabled to send an access request, it randomly selects one of the time slots

in the Contention Window and transmits an RTS packet. In case of collision events, requests to access are forbidden in order to avoid unstable situations. Collisions may take place when more than a node request for transmission using the same time slot in the Contention Window. In this case the access requests will collide and the nodes involved in the collision will enter the CRQ, getting a valid value for its pRQ. In the CRQ nodes will wait for its turn to transmit a new access request in order to resolve the collision. That is, when its pRQ gets the value 1 then it will transmit an access request in the next frame.

In case of a unique access request in one of the m slots within the Contention Window, the requested node will enter the DTQ getting a valid pTQ value ($pTQ > 0$). In this queue it will wait for its turn to transmit a data packet and it will be inhibited from sending new access requests. That is, when its pTQ gets the value 1 then it will transmit a data packet in the next frame. Furthermore, an ALOHA-like data access transmission is allowed when the DTQ is empty, i.e. if the DTQ is empty nodes are allowed to transmit data packets without previously requesting the channel. This feature allows the presence of collisions in data transmissions, but it also improves the delay performance for light traffic conditions. Figure 1 shows the frame structure of the MAC protocol.

III. CROSS-LAYER TECHNIQUE DESCRIPTION

The aforementioned MAC protocol includes an inherent PHY-MAC Cross-Layer dialogue, as PHY layer state information from the receiver node is broadcasted to the MAC layer of the transmitter node, in order to manage the transmission queue. To be more precise, the RTS packet is used by the AP to estimate the channel varying characteristics of each node. Furthermore, downlink CTS packets that are broadcasted by the AP in each time frame can include information about the available transmission rates for each node in DTQ. Therefore, this queue is reordered giving priority to nodes with higher transmission rates that means to nodes with better channel conditions.

In the proposed Cross-Layer technique the AP estimates the Signal to Noise Ratio (SNR) of each node based on the signal strength of the received access request (RTS packet). Having predefined thresholds for the signal to noise ratio, the AP can assign the transmission rate of each one. Nodes' rate information is included in the downlink CTS packet that is broadcasted by the AP. In this way, system's nodes receive the downlink packet and the MAC layer of each one is aware of its own rate as well as the available rate of the other nodes. Therefore, the DTQ is reordered giving higher positions to those nodes with the higher available transmission rate. In the case that more than one node has the maximum possible rate available, the highest priority in DTQ is given to that with the

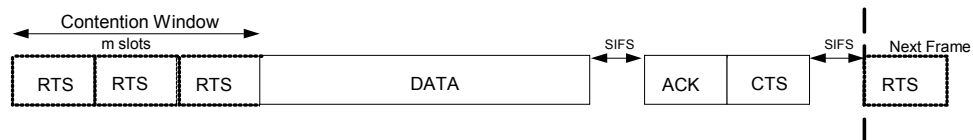


Figure 1 DQCA frame structure

minimum pTQ (the closest node to the head of the queue).

It has to be noted that the downlink information concerning nodes' available rates is transmitted by the AP in the same order as the nodes in the DTQ. Thus, the nodes with the same transmission rate will easily know their pTQ value that means their position in the queue. Therefore, they will be aware if they have permission to transmit a data packet in the next frame.

IV. SIMULATION SCENARIO

In order to evaluate the proposed Cross-Layer mechanism, a WLAN system in infrastructure mode is considered. The simulated scenario consists of a 200x200m region where 20 data nodes move with 1 m/s speed corresponding to a 30 ms coherence time in the 2.4 GHz frequency region. Traffic generation is modeled as Poisson with exponentially distributed packet sizes and average size of $10 \cdot L$, with L being the number of bytes transmitted in each frame.

The wireless channel is modeled as a two state discrete Markov chain. The channel can be in one of the two possible states with certain probabilities, 0.8 for the good state and 0.2 for the bad state, as it is shown in Table I. Within each state, a uniform random variable determines the SNR value for the transmission, while the channel of the nodes is updated in intervals equal to the coherence time. A low mobility scenario and slowly varying channel have been considered in the simulations. Therefore, the previously described scheduling based on the SNR estimation can be implemented.

TABLE I. CHANNEL MODEL SETTINGS

Channel State	Probability	SNR (uniform)
<i>Good</i>	0.8	[10-20] dB
<i>Bad</i>	0.2	[0-10] dB

As previously mentioned, a set of SNR thresholds should be defined in order to select the appropriate data rate in the physical layer. These thresholds have been selected based on the results presented in [11] and are shown in Table II. Ideal SNR detection and perfect rate selection scheme have been assumed in the simulations.

TABLE II. DATA RATE THRESHOLDS

Rate	1 Mbps	2 Mbps	5.5 Mbps	11 Mbps
SNR	<4 dB	4-7.5 dB	7.5-11 dB	>11 dB

The downlink packet (ACK+CTS) that is transmitted by the AP at the end of each DQCA frame consists of 2 bytes for the Frame Control (FC) field, 6 bytes for the CTS information, 1 byte for the ACK and 4 bytes for the FCS (Frame Control Sequence).

On the other hand, RTS access request packets can be minimized, as the PHY layer for the DQCA operation only needs to detect three different states (empty, success, collision) and no information needs to be carried [12]. Thus, RTS packet size is expressed in terms of transmission time and lasts $2 \mu\text{s}$.

Furthermore, all control packets (RTS, CTS, ACK) are sent at the minimum rate of 1 Mbps in order to ensure reliable transmission. Overhead caused by RTS, CTS and ACK transmissions has been taken into account both in the throughput and in the mean delay. Other parameters such as the MAC header, PHY header and the SIFS interval were taken from the 802.11b extension of the standard. Table III summarizes the values of the main parameter used in the system layout.

TABLE III. SYSTEM PARAMETER VALUES

No. of slots in the CW	3
SIFS	$10 \mu\text{s}$
Propagation delay	$1 \mu\text{s}$
PHY header	$96 \mu\text{s}$
MAC header	34 bytes
Data Packet Length	100-500-2312 bytes
DL packet (ACK+CTS)	13 bytes
RTS	$2 \mu\text{s}$

V. SIMULATION RESULTS

In order to examine the performance of the previously described technique, the net throughput in Mbps versus the offered load for the system using different packet sizes is depicted in Figure 2. Throughput is defined as the ratio of the correctly received bits per second. It can be seen that a significant gain can be achieved using the mentioned Cross-Layer mechanism added to the normal DQCA operation. Furthermore, the greater the size of the data packets is, the higher the gain in terms of mean throughput is obtained. As a benchmark figure, the throughput is improved up to 75% for packets size of 2312 bytes. The obtained gain is due to the fact that priority is given to nodes with better channel (i.e. higher available transmission rates). Therefore, the number of packets transmitted with higher rates increases and so the overall system's throughput is improved.

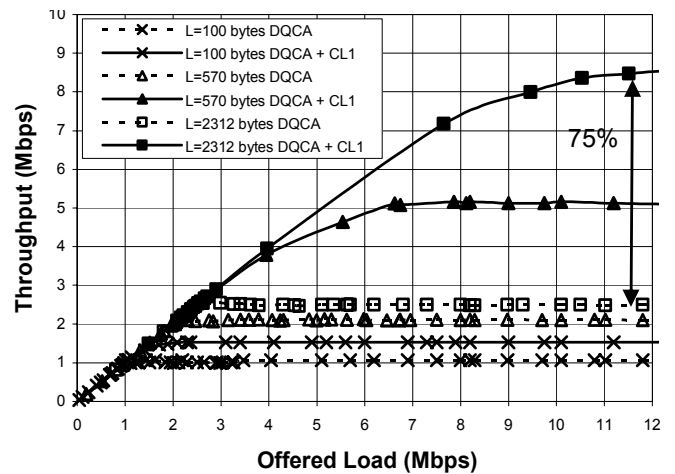


Figure 2. Throughput versus offered load with and without cross-layer techniques

Figure 3 compares the mean packet delay versus the offered load of the DQCA with the proposed Cross-Layer mechanism to those of the DQCA operation without Cross-Layer. As packet delay is defined the period of time since a data packet is generated by a node until it is completely transmitted to the Access Point. It can be seen that when the proposed Cross-Layer technique is applied, the mean packet delay decreases due to the more efficient use of the wireless channel. Since more packets are transmitted with higher rates, the frames' duration last less and so the average packet delay is reduced. It can be also observed that the greater the packet size is, the higher the mean delay reduction is achieved. It is worth mentioning that for a certain value of mean delay, the offered load of the system is increased when the proposed cross-layer technique is applied

These results show that, even though DQCA itself can improve significantly the performance of a WLAN system [10], it can be further enhanced in terms of throughput and mean packet delay when Cross-Layer concepts are used in order to schedule packet transmissions.

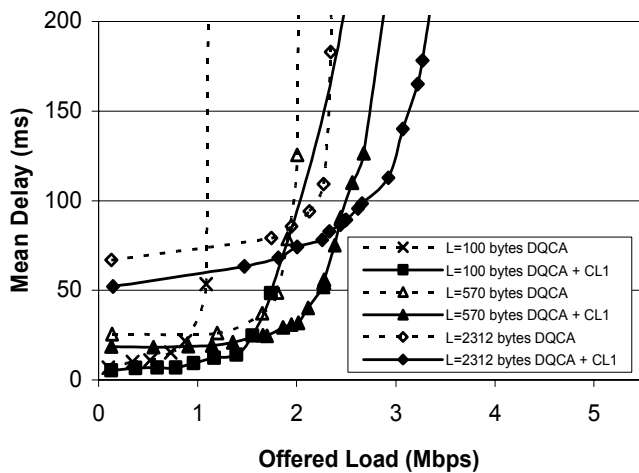


Figure 3. Mean delay versus offered load with and without cross-layer techniques

VI. CONCLUSIONS

A novel PHY-MAC cross-layer strategy for WLAN systems has been presented and its performance has been analysed for a representative system scenario. Computer simulations have been carried out to evaluate and quantify the benefits of the proposed technique. In particular, a throughput improvement up to 75% can be achieved over the maximum throughput obtained with DQCA protocol without cross-layer concepts. On the other hand, a mean packet delay reduction is achieved due to the inherent cross-layer capabilities. Finally, we can conclude that the proposed scheme has shown remarkable benchmark values and it can be considered for future WLAN systems.

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