



A Novel Method for Weighted Throughput Fairness in Contention-Based WLANs with Multiple Priority Levels

Chun Shi¹, Zhi-qun Zheng¹, Zheng-jie Deng¹, Yu-juan Wang²,
and Shu-qian He¹(✉)

¹ Hainan Normal University, Haikou 571158, People's Republic of China
76005796@qq.com

² Xinhua College of Sun Yat-Sen University, Guangzhou 510520,
People's Republic of China

Abstract. Focus on the weighted throughput fairness in IEEE 802.11e networks, we propose an adaptive and full-distributed access mechanism. We define a new parameter of Detection Window (DW) that has the same sizes for all nodes. During the process of DW, nodes detect messages of CSI and estimate active node number to set sizes of CW according to itself priority level. We set optimal CW sizes for nodes with the highest priority level and increase CW sizes for nodes with lower priority levels. The selected CW determines sizes of backoff windows and attempt probability of channel access, which can be reflected weighted throughput fairness corresponding to multiple priority levels. The simulation results confirm the validity and good scalability of the proposed access mechanism among multiple priority levels.

Keywords: IEEE 802.11e · Medium access control · EDCA · Weighted throughput fairness

1 Introduction

THESE applications of different traffic types, such as voice, video or data traffic, need multiple Quality of Service (QoS) levels. The weighted throughput fairness corresponding to multiple priority levels (MPLs) is one of the main research directions to improve the QoS performance of network. The IEEE 802.11 family provides the most popular usage in wireless networks. The methods in IEEE 802.11 cannot solve the multiple transmission times of the same nodes during one transmission cycle, which results in the bad fairness.

In this work, we focus on contention-based methods (DCF mechanism and EDCA mechanism) for detail analyses of CSI measurement. We propose an Access Mechanism with Multiple Priority Levels (AMMPL) to analyze performance of weighted throughput fairness.

2 State of the Art

There are two main contention-based methods: DCF mechanism and EDCA mechanism in [1]. Except for some access parameters, these two methods have the same processes of data transmission like Fig. 1.

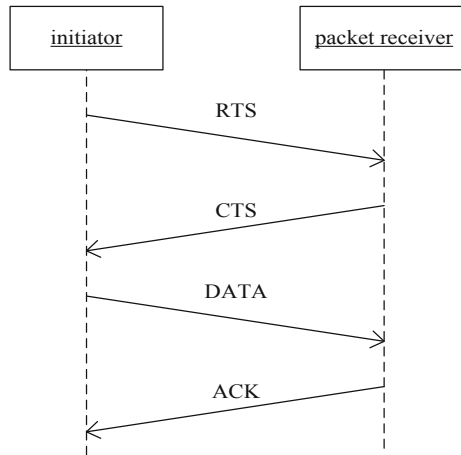


Fig. 1. RTS/CTS/DATA/ACK mode

In Fig. 1, the initiator detects the status of channel. If the channel is idle, the initiator sends RTS frame to reserve the channel for the next data transmission. If the packet receiver gets the RTS frame and analyzes that it is the destination receiver of the RTS frame, the packet receiver sends a CTS frame to the initiator, which means that the packet receiver is ready to accept data frame and announces the occupation of the shared channel for the later data transmission. After receiving the CTS frame, the initiator sends a data frame and waiting the ACK frame. If the packet receiver gets the accurate data frame, it sends ACK frame back to the initiator that means it has gotten the accurate data frame. And then, the full transmission is done.

If the initiator cannot receive the ACK frame during certain time, it judges the failed data transmission. The length of the data packet and the waiting time for ACK frame are the total time for the initiator to determine the collision of data transmission. To reducing the waste time of judgment process of collision, the RTS/CTS frames are used for the large length of data packet due to the large collision judgment time.

If the length of data packet is small, however, nodes can exchange messages without RTS/CTS frames. There is a threshold to determine the usage of RTS/CTS frames to reserve the channel. The usage of RTS/CTS frames, however, increases the overhead of throughput due to the exchange time especially in networks with large nodes.

With the data transmissions of the initiator and the receiver, other nodes detect the activities of the shared channel and defer their data transmissions according to the status of the channel.

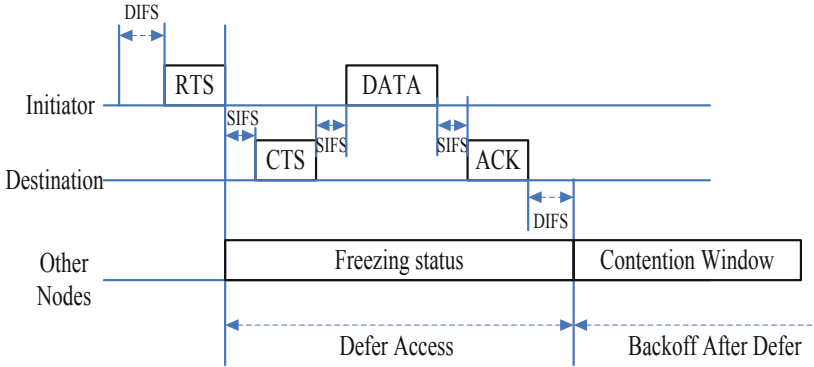


Fig. 2. Access status of other nodes

As shown in Fig. 2, other nodes get into a freezing status if they receive the accurate RTS frame of the initiator. And other nodes stop backoff processes or activities of data sending for avoiding data collisions with the initiator and the destination. After the data transmission between the initiator and the destination, other nodes begin the backoff processes again for reserving the shared channel.

During these processes of data transmission, there are some transmission collision events among two nodes and more transmitting at the same time. If nodes judge the transmission collision event, they normally adjust access parameters for next retransmission. In this work, we focus on the adjustment rules of CW and show the rules of CW in Fig. 3.

As shown in Fig. 3, the adjustment rule of CW can be described as

$$CW_{i+1} = \text{MIN}\{(CW_i + 2) * 2 - 1, CW_{\text{max}}\} \tag{1}$$

In (1), $i(i \in (0, 1, 2, \dots))$ means the transmission times. And we have $CW_0 = CW_{\text{min}}$. In IEEE 802.11, both methods of DCF and EDCA have the fixed sizes of CW $\{CW_{\text{min}}, CW_{\text{max}}\}$. Nodes select sizes of backoff window randomly in CW and begin decrement processes of backoff window. If sizes of backoff window reach to zero, nodes begin to send data. If there is a successful data transmission, nodes reset CW sizes. If there are collisions, nodes will double CW sizes.

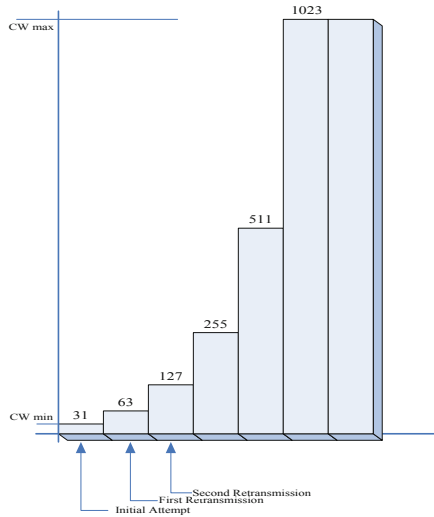


Fig. 3. Adjustment rules of CW

The DCF mechanism uses the same set of access parameter for all nodes, and the EDCA mechanism uses different sets of access parameter for multiple priority levels. In EDCA mechanism, nodes with higher priority level have smaller sizes of CW than that of nodes with lower priority level. Without knowledge of channel status information (CSI), fixing range of CW sizes for nodes with multiple priority levels cannot obtain the expected results as analyses in [2, 3] and [4].

Some works focus on the proportional fairness in multiple priority levels or multi rates WLANs in [5] and [6]. A game theoretic approach is used to analyze model of DCF for tuning CW dynamically in [7]. Collided packets are used to adjust next transmission time for collision-free access in [8]. Some nodes are dependent on itself statuses of data transmission (successful transmission or collision) in [1]. Some nodes adjust CW sizes based on messages detected from decrement processes of backoff window in [3] and [9].

In above adaptive optimizations, the key problem is the calculation of CSI and estimation algorithm of dynamic network conditions (active node numbers in this paper). The idle slot intervals are analyzed when nodes have different CW sizes in [10]. The estimation algorithm with multiple functions is used to track the node number in [2], which is complicated and should be simplified. A searching algorithm is used to find the node number in [11]. An extended Kalman filter is used to obtain the numbers of active queues in [12]. Some optimizations can be found in [13] and [14].

To obtain messages of CSI in homogeneous network with DCF mechanism, the normal window used by adaptive access mechanisms is the backoff window that nodes select in CW in [2]. During their decrement processes of backoff window, nodes detect events of data transmission and calculate message of CSI (for example, idle slot intervals, slot utilization or collision rate). These mechanisms can improve the throughput and fairness of each node with adaptive adjustment rules between access

parameters and message of CSI in homogeneous networks. For networks with QoS requirements, the EDCA mechanism presents an application mode. A node itself generates all data with different priority levels. The node sets different sizes of CW for every type of traffics according to priority levels in its transmission queues. It's the number of packets with multiple priority levels that has the important effect on weighted throughput fairness. And it's not easy to add some traffic loads of special priority level. Some adaptive mechanisms of [2, 3] and [9] overlap detection processes on backoff processes, which mean that nodes normally sense messages of CSI during their decrement processes of backoff window. These detection processes work well in DCF mechanism and lost their advantage in EDCA mechanism.

In QoS networks, nodes with MPLs have different sizes of backoff windows and obtain different messages of CSI by overlapping detection processes of CSI on decrement processes of backoff window. Nodes with high priority levels usually use small sizes of CW and select small backoff window to access channel quickly. Nodes with low priority levels, however, use large sizes of CW and select large backoff window, which means more accurate status of CSI than nodes with higher priority levels due to long sensed window. It's unfit to detect messages of CSI during the decrement processes of backoff window in QoS networks. Due to lack of accurate messages of CSI, there are less contention-based mechanisms to analyze throughput performance of three and more priority levels.

In this paper, we propose the AMMPL mechanism and the method can have the main contributions:

- We present a new adjustment rule of CW, in which nodes with the highest priority levels are set the optimal CW sizes and nodes with lower priority levels according to their priority levels have been increased the sizes of CW.
- We define a new parameter of Detection Window (DW) and propose an adjustment rule of DW sizes, which separates detection processes from processes of backoff window.

3 Adaptive Access Mechanism with Multiple Priority Levels

In this section, we focus our interest on the analyses on network with two WPLs, which can be verified in three WPLs. Firstly, we introduce some main results of AMOCW mechanism in [2]; and then, we define a parameter of Detection Window (DW) that has an adjustment rule of Binary Increase and Binary Decrease, which can be used for QoS networks; lastly, we develop adjustment rules of CW in network with two priority levels.

3.1 Throughput Ratios of Priority Levels

Before presenting adjustment rules of CW sizes, we assume that there are two types of WPLs (Class high (H) and Class Low (L)) corresponding to the higher throughput S_H and the lower one S_L for the convenience of analysis. Each node in network is belonged to only one priority level. We obtain

$$S_H : S_L = \rho_H : \rho_L \quad (2)$$

where ρ_H and ρ_L are throughput ratios among nodes with the higher priority level (nodes_H) and nodes with the lower priority level (nodes_L) ($\rho_H \geq \rho_L$).

Normally, we set $\rho_L = 1$. For case of $\rho_H > \rho_L$, throughput of nodes_H (ρ_H) is larger than that of nodes_L (ρ_L). If nodes_L finish one data transmission, nodes_H should send ρ_H/ρ_L traffic loads for given the same length of packets.

3.2 AMOCW Mechanism

AMOCW mechanism in [2] is fit for homogeneous WLANs and can reach high throughput and fairness. By introducing a parameter of CW index (CWI (θ)), the mechanism builds approximately linear relationship between CW sizes (W for short) and active node number (N) in the network.

$$W \approx \theta \cdot (N - 1) \quad (3)$$

And it further designs a calculation of idle slot intervals n as:

$$n = E_{\text{SLOT}} / \left(E_C + E_S - \sum_{i=1}^m (E_{S_i} - 1) \right) \quad (4)$$

where E_{SLOT} is the values of idle slot time. E_S and E_C are successful data transmission times and collision times detected in the channel, respectively. m is the active node number in the networks that the tagged node detects.

3.3 Definition of Adjustment Rules of DW

In networks with multiple priority levels, nodes should have the same results of CSI although multiple access parameters.

We introduce a new parameter of DW, which sets the same sizes for all nodes. We define a Binary Increase/Binary Decrease adjustment rule of DW as follow,

$$\begin{cases} DW_{\text{new}} = \alpha \cdot DW_{\text{cur}} & (n \leq n_{\text{opt}}) \\ DW_{\text{new}} = \beta \cdot DW_{\text{cur}} & (n > n_{\text{opt}}) \end{cases} \quad (5)$$

where DW_{cur} and DW_{new} mean parameter that nodes are using and predicted values, respectively. n_{opt} is the optimal idle slot intervals between two data transmissions, which can be calculated in advance with the determined parameters. α and β are coefficients used to adjust values of DW (in this paper, we set $\alpha = 2$ and $\beta = 1.5$). The adjustment rules of DW have the simple function that is independent from the adjustment rules of CW. During the process of DW, the tagged node can detect the status of CSI and calculate the idle slot intervals between two data transmissions.

3.4 Estimation Algorithm of Node Number

Based on (4) and (5), we can obtain values of CSI. And then, we further give the estimation algorithm of node number with values of CSI. For simplicity, we present a linear estimation algorithm of node number as follow,

$$N_{\text{new}} = \frac{n}{n_{\text{opt}}} N_{\text{cur}} \quad (6)$$

where N_{cur} and N_{new} are values of node number that the tagged node is using and predicted values, respectively. Compared with estimation algorithm in [2], this estimation algorithm is simply and has the same effective.

3.5 Adjustment Rules of CW Sizes

The throughput can be connected with parameter τ that means attempt probability of data transmission in a slot. During one data transmission cycle, nodes with multiple priority levels should send packets according to their throughput ratios (as like, ρ_H , ρ_L), which can be seen as probability of channel access.

$$\rho_H : \rho_L \approx \tau_H : \tau_L \quad (7)$$

Based on $\tau = 2/W$, we obtain

$$\rho_H : \rho_L \approx 2/W_H : 2/W_L \quad (8)$$

We select an adjustment that nodes_H have the optimal CW sizes (W_{opt}), which is the smallest values of CW than nodes with other priority levels.

$$W_H = W_{\text{opt}} \approx \theta_{\text{opt}} \cdot (N - 1) \quad (9)$$

where θ_{opt} has been analyzed in [2]. With the optimal parameter W_{opt} , nodes can hold the fitful channel status that has low collision probability and high throughput. Based on (7) and (9), we develop CW sizes for nodes with other priority levels as

$$W_L \approx (\rho_H/\rho_L) \cdot \theta_{\text{opt}} \cdot (N - 1) \quad (10)$$

According to (8)–(10), nodes with multiple priority levels have different CW sizes to meet weighted throughput fairness. Nodes_H have the smaller CW sizes and nodes_L have the larger CW sizes. These CW sizes determine backoff window to access the channel. And then, the backoff window of nodes_H is smaller than that of nodes_L, which means that the calculated results of CSI will be different if nodes detect the messages of CSI during backoff window.

We define some main functions of DW as follows:

- **Calculation:** Nodes detect status of CSI and count events of data transmissions to calculate idle slot intervals between two data transmissions;

- **Estimation:** Nodes estimate active node number in the channel, in which nodes should eliminate the bad impact of multiple transmission times of the same node.
- **Adjustment:** Nodes adjust sizes of DW based on the estimated node number and keep the values of estimated node number for adjustments of CW. With determined CW sizes, nodes select backoff window randomly in CW and begin decrement process as normal work like EDCA mode.

4 Computer Simulation and Analysis

In this section, we use the OPNET (version 14.5) modeler to verify the proposed mechanism and mainly compare with EDCA mechanism. Each node is in saturation state and uses RTS/CTS frames to reserve the ideal channel. According to [2], we simply set $\theta_{opt} = 10$ for nodes_H and throughput ratios of three priority levels are defined as $\rho_H : \rho_M : \rho_L = 3 : 2 : 1$ ($\rho_L = 1$) corresponding to the highest priority level, the middle priority level and the lowest priority level. The CW sizes are determined according to (8)–(10). The ranges of EDCA mechanism are W_H ([16, 64]), W_M ([24, 96]) and W_L ([48, 192]). Other main simulation parameters are the same listed in [2].

As shown in Fig. 4, the simulated throughput ratios of AMMPL mechanism are around theoretic values, which confirm the validity and good scalability of the proposed mechanism. Due to reasonable division of functions between DW process and CW process, the mechanism provides the accurate measurement of CSI and estimation algorithm of active node number in an independent DW process. Based on estimated node number, the linear adjustment rules of CW guarantee throughput ratios according to multiple priority levels. Compared with AMMPL mechanism, the EDCA mechanism cannot hold the throughput ratios between nodes with higher priority levels (nodes_H or nodes_M) and nodes_L. Due to lack of accurate CSI in EDCA mechanism, both throughput ratios (High : Low and Middle : Low) increase with increment of node number, which means that nodes with higher priority levels have more throughput than that of nodes_L. The throughput ratios between nodes_H and nodes_M are near the theoretic values both in AMMPL mechanism and EDCA mechanism.

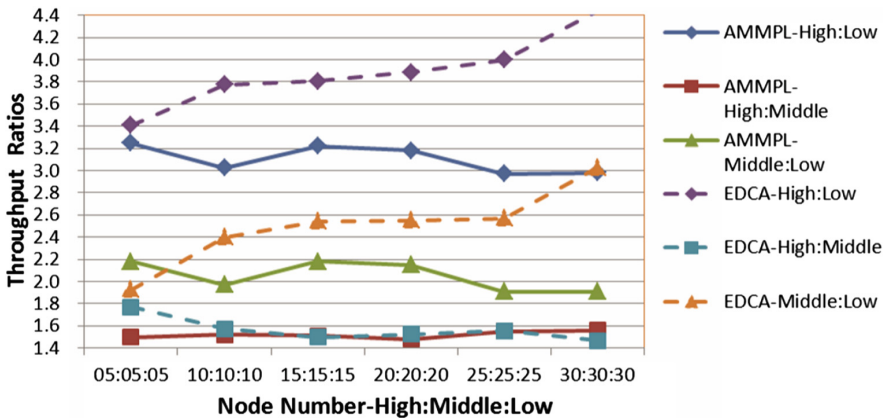


Fig. 4. Throughput ratios

5 Conclusion

By defining a new parameter of DW to calculate events of data transmission, we obtain the accurate values of CSI for better estimation algorithm of node number. And then, we adjust the optimal CW sizes for nodes with the highest priority levels and increase CW sizes for nodes with low priority levels corresponding to their throughput ratios based on the estimated node number.

In the future work, we will study the history data of DW for better estimation algorithm of active node number. These access parameters and more performance in networks with multiple priority levels will be gotten further analysis.

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