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Achieving optimal performance in IEEE 802.11 wireless LANs with the combination of link adaptation and adaptive backoff ☆

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Abstract

IEEE 802.11 is one of the most popular wireless LAN standards [Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications, IEEE Standard 802.11, August 1999]. In the paper, we propose a simple analytical model, which helps one obtain deep insight into the mechanism of achieving optimal performance by using IEEE 802.11 DCF (Distributed Coordination Function) protocol. The first contribution of this paper is the analysis of the optimal operation point where maximum goodput can be achieved. Through the analysis, we answer some fundamental questions about the existence and the uniqueness of the optimal operation point; about the maximum system goodput can be achieved; about the existence of a simple rule to check out if the system operates under the optimal state or not; and how do the data transmission rates, which is dependent on the selected physical transmission mode, and packet transmission errors, caused by channel fading and (or) interference, affect the final system performance. Another contribution is the proposal of a simple distributed adaptive scheme "LABS" (i.e., Link adaptation and Adaptive Backoff Scheme), which makes the system operate under the optimal operation point and, at the same time, achieves some pre-defined target service differentiation ratio between different traffic flows. In the LABS, two adaptive schemes are combined: one is the so called "Link Adaptation" scheme, which dynamically selects an optimal modulation mode at a given time so as to improve the achieved system goodput; the other one is the so called "Adaptive Backoff" scheme, which adaptively adjusts the minimum contention window size of each sending node to guarantee that the system operates under (or near) the optimal operation point. Results obtained in the paper are relevant to both theoretical research and implementation of real systems.

Keywords: Wireless LAN; IEEE 802.11 MAC; Service differentiation; Performance analysis; Link adaptation

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1. Introduction

In the literature, performance evaluation of IEEE 802.11 DCF has been executed by using simulation [2] or by means of analytical models [3–8]. One of the core mechanisms for DCF is the backoff procedure. In [3–5], constant or geometrically distributed backoff window sizes have been considered. In [6], an exponential backoff with only two stages is modeled by using a two-dimensional Markov chain. In [7], a more general model that accounts for all the exponential backoff protocol details is proposed. In [8], the model is further extended to the case where packet transmission errors are considered. Instead of using stochastic analysis, in [9], the average value for a variable is used, which results in an approximate but effective analysis.

However, in the above literatures, only one type of traffic is considered. In order to support service differentiation, various enhancements for IEEE 802.11 DCF have been proposed, such as those proposed in [10–13]. In these literatures, the basic idea of achieving service differentiation is to allocate different access parameter set to different traffic flows so as to control the backoff procedures of different traffic flows, which makes it easier for traffic flows with higher priority to access channel resources. Recently, EDCA (Enhanced Distributed Channel Access) is defined in IEEE 802.11e [14]. In EDCA, four backoff entities are supported within one 802.11e node, with each backoff entity corresponding to a particular Access Categories (AC). Service differentiation for each AC is supported by using AC-specific contention parameters, called EDCA parameter set. Arbitration Inter Frame Space (AIFS[AC]), minimum contention window size $CW_{min}[AC]$ are included in EDCA parameter set for each AC. With shorter AIFS[AC] or (and) smaller $CW_{min}[AC]$, the corresponding backoff entity in a 802.11e node has higher priority to access channel resources, which brings about relatively better QoS for the corresponding traffic flows. Moreover, in order to gain deeper insight into the enhanced IEEE 802.11 DCF with service differentiation support, system modeling and performance analysis are proposed, such as those proposed in [15–19].

In order to improve the system performance, apart from enhancing the backoff mechanism defined in IEEE 802.11 DCF, another technique called "Link Adaptation", which is the mechanism of selecting one out of multiple available transmission rates at a given time, is studied in literatures, such as those in [20–23]. It is well known that the higher the transmission rate is, the higher the packet error rate is. When the channel state is good, system performance benefit more from improving the transmission rate. Whereas, under the case of bad channel state, it benefits more by lowering the transmission rate, which helps improve the robusticity of the transmission scheme. Therefore, the basic idea of link adaptive schemes is to find out the optimal tradeoff between transmission rate and packet error rate, which brings about optimal system performance over time-varying wireless channels. The AutoRate Fallback (ARF) protocol is used in Lucent Technologies' WaveLAN-II networking devices [20]. In ARF, the transmission rate alternates between 1 and 2 Mbps physical mode, which is based on the idea of keeping track of a timing function and detecting the number of missed ACK frames. In [21], a Receiver-Based Auto-Rate (RBAR) protocol is proposed. The scheme is based on the RTS/CTS (Request-To-Send/Clear-To-Send) mechanism. The basic idea of RBAR is that the receiver detects the channel quality and feeds this information back to the transmitter by using modified CTS frame. The proper transmission rate is chosen after the transmitter received the information about the estimated channel quality. In the above two schemes, detailed analysis, which helps one to obtain deep insight into the system performance is not given. In [22], the authors propose a MPDU (MAC Protocol Data Unit)-based link adaptation scheme based on detailed goodput analysis. The basic idea of the scheme is that the wireless node computes offline a table of physical modes indexed by the system status and each entry of the table is the best physical mode in the sense of maximizing the expected goodput. Although, a detailed analysis is proposed in [22], a more general case where there are a large number of traffic flows sharing the same wireless channel is not considered. It is evident that in order to optimize the system performance, packet collisions between different traffic flows and the corresponding backoff mechanism should be consider. Another problem in [22] is that the obtained analytical results are still complex so that it can be only used in offline manner. In [23], a theoretical model for Medium Access Control (MAC) and physical (PHY) layer protocols in IEEE 802.11 WLANs is proposed, which allows assessing the effect of distinct modulation schemes and channel models on the system performance. However, the proposed performance analysis is not deep enough to find out how to optimize the system performance.