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Modeling and optimization of wireless local area network

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Abstract

As wireless local area network technology is gaining popularity, performance analysis and optimization of it becomes more important. However, as compared to wired LAN, wireless channel is error-prone. Most of the existing work on the performance analysis of IEEE 802.11 distributed coordination function (DCF) assumes saturated traffic and ideal channel condition. In this paper, modeling of DCF is analyzed under a general traffic load and variable channel condition. A more realistic and comprehensive model is proposed to optimize the performance of DCF in both ideal and error-prone channels, and for both the basic scheme of DCF and DCF with four-way handshaking. Many factors, such as the number of contending nodes, the traffic load, contention window, packet overhead and channel condition, that affect the throughput and the delay of a wireless network have been incorporated. It is shown that under error-prone environment, a trade-off exists between the desire to reduce the ratio of overhead in the data packet by adopting a larger packet size, and the need to reduce the packet error rate by using a smaller packet length. Based on our analytical model, both the optimal packet size and the optimal minimum contention window are determined under various traffic loads and channel conditions. It is also observed that, in error-prone environments, optimal packet size has more significant improvement on the performance than optimal contention window. Our analytical model is validated via simulations using ns-2.

Keywords: IEEE 802.11; Optimization; Throughput; Performance evaluation; Packet error rate

1. Introduction

Wireless local area network (WLAN) offers the benefit of traditional LAN technologies while greatly increasing the flexibility of not being tethered to a cable. With its increasing popularity, the underlying IEEE 802.11 protocol has become widely deployed [1]. Although advances in the wireless physical layer have dramatically increased the data rate that 802.11 can support [2], all the emerging 802.11x schemes are still using the same MAC protocol based on carrier sense multiple access with collision avoidance (CSMA/CA) [4]. It is important to analyze the performance of the IEEE 802.11 accurately since an accurate analytical model can be helpful to derive the upper bound for the performance, and also provides us with insights on how to optimize the protocol. Most of the existing work on the performance analysis assumes the presence of ideal channel and saturated traffic. In these models [5–8], the performance measures, such as the throughput and the average delay depend only on the backoff parameters and the network configuration. Thus, distributed coordination function (DCF) performance optimizations are done primarily to minimize the contention by choosing an optimal contention window size [8]. Intuitively, traffic load and packet error rate (PER) also affect the maximal achievable performance. As already pointed out in Ref. [10], there exists a tradeoff between the need to reduce the ratio of overhead in the data packet by adopting larger packet size, and the need to reduce the PER under bad channel conditions by using smaller packet length.

1.1. Related work

Since its standardization [2], there has been extensive research work on the performance of 802.11 CSMA/CA. One of the difficulties in analyzing CSMA/CA in 802.11

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DCF lies in modeling the exponential backoff mechanism. Under saturated traffic, each node can always be said to have a packet ready to transmit, and a packet can be assumed to collide with packets from other nodes in a constant probability. This collision probability is dependent on the number of contending nodes and the backoff parameters, such as the minimum contention window ($\mathrm{CW}_{\min}$) and maximum backoff stage. Based on this collision probability, the probability of each node sending a packet can be derived. Thus, CSMA/CA under saturated traffic is assumed to follow a p-persistent protocol [5–8,11–15]. In the p-persistent analysis of the 802.11 DCF, the throughput can be optimized by choosing an optimal sending probability p [8,9], which can be achieved by employing an optimal uniformed backoff window, or by utilizing an optimal minimum contention window while keeping the exponential backoff mechanism.

The work mentioned so far assumes the presence of perfect channel condition. Actually, wireless channel is error-prone. Moreover, when there are transmission errors, the sender does backoff similar to the situation when a collision occurs, as the sender cannot receive acknowledgement from the receiver. In error-prone environment, the PER mainly depends on the bit error rate (BER) and the packet length [3]. When the packet size is larger, the packet transmission is more likely to be corrupted. If the packet size is smaller, the packet is more likely to be received correctly, but the increased overhead ratio will degrade the throughput. Therefore, a tradeoff exists in choosing the packet size.

1.2. Our major contributions

In this paper, different from existing models in the literature, a more realistic and comprehensive model is proposed for the performance analysis and optimization of DCF. The major contributions of this paper are summarized as follows:

To optimize the performance of 802.11 DCF, we need to define an accurate model, and then determine how different factors affect the performance of the 802.11 DCF. These factors include network configuration, traffic load (which determines the intensity of collisions), channel condition (which determines the transmission error rate), and the packet size (which determines the overhead ratio and the PER). A comprehensive analysis and optimization of DCF require all these factors to be incorporated. In this paper, we propose a unified analytical model to analyze the throughput and the delay in DCF with all the aforementioned factors. The analytical results seem to match very well with the simulation results, which indicate that our analytical model is fairly accurate.

Performance should be related with the traffic load. Although many results for saturation throughput and delay of 802.11 DCF can be found in previously published papers [5–8], there is no guarantee for the analysis carried out under saturated traffic to remain valid in the case of unsaturated traffic. Our analytical model uses a traffic model, which accounts for both un-saturated and saturated traffic conditions. Our results indicate that compared with the basic scheme of DCF, DCF with RTS/CTS is beneficial for heavy traffic load; however, it does not result in any significant throughput improvement for light traffic load. Moreover, the optimal packet size is also dependent on the traffic load.

The performance of DCF in error-prone channel is analyzed in Refs. [13–16] by considering the retransmissions due to packet errors. However, all these papers are limited to saturated traffic. Furthermore, none of them analyzes the trade-off in choosing packet size. The idea of optimal frame length is presented in Ref. [10]. Although it provides insights on the optimization of MAC layer under error-prone environment, it does not consider the characteristics of CSMA/CA such as the contention and exponential backoff mechanism. Thus, it cannot be applied to 802.11 DCF directly. Our paper focuses on the performance analysis and optimization of 802.11 DCF under variable traffic loads and channel conditions, and determines how packet size and channel conditions affect the performance. Based on this analytical framework, the maximum throughput is achieved by determining both the optimal packet size and the minimum contention window under a given traffic load, network configuration and channel conditions.

The remainder of this paper is organized as follows. Section 2 gives the system model and analysis of packet sending probability. Performance analysis of DCF under both ideal and error-prone channel is presented in Section 3. In Section 4, we give the analytical and simulation results. The final part is the conclusion.

1.3. Overview of the IEEE 802.11 DCF

DCF protocol is basically CSMA/CA protocol with exponential backoff [2]. Before sending data, nodes listen until the medium is idle for a period of DCF inter-frame space (DIFS) duration. If no confirmation is received from the receiver after the sender sends a packet, the sender can assume that the receiver has not received the packet. This can be due to either collision or packet corruption. Upon this, the sender will backoff according to the exponential backoff rule.

There are two schemes for DCF [2]: four-way handshaking scheme and the basic scheme. In four-way handshaking, the sender first sends out a short request-to-send (RTS) packet before it transmits a packet. If the receiver hears the RTS, it responds with a short clear-to-send (CTS) packet. After this exchange, the sender sends its data packet. When the packet is received successfully, the receiver transmits an acknowledgement (ACK) packet. In the basic scheme, RTS/CTS is not used.