Wireless Networks 7, 159–171, 2001

A Capacity Analysis for the IEEE 802.11 MAC Protocol

Y.C. TAY and K.C. CHUA
National University of Singapore

Abstract. The IEEE 802.11 MAC protocol provides shared access to a wireless channel. This paper uses an analytic model to study the channel capacity – i.e., maximum throughput – when using the basic access (two-way handshaking) method in this protocol. It provides closed-form approximations for the probability of collision p, the maximum throughput S and the limit on the number of stations in a wireless cell.

The analysis also shows that: p does not depend on the packet length, the latency in crossing the MAC and physical layers, the acknowledgment timeout, the interframe spaces and the slot size; p and S (and other performance measures) depend on the minimum window size W and the number of stations n only through a gap $g = W/(n-1)$ – consequently, halving W is like doubling n; the maximum contention window size has minimal effect on p and S; the choice of W that maximizes S is proportional to the square root of the packet length; S is maximum when transmission rate (including collisions) equals the reciprocal of transmission time, and this happens when channel wastage due to collisions balances idle bandwidth caused by backoffs.

The results suggest guidelines on when and how W can be adjusted to suit measured traffic, thus making the protocol adaptive.

Keywords: IEEE 802.11 MAC protocol, capacity analysis, saturation throughput, closed-form approximation, analytic validation, window size adaptation

1. Introduction

With the proliferation of mobile computers, their limited computing resources, and the popularity of Internet access, there is a growing need for these computers to be networked. In response, the IEEE 802.11 study group proposed a standard for wireless local area networks [8]. This standard specifies the characteristics of the physical layer, as well as the medium access control (MAC) protocols in the link layer.

There are essentially two MAC protocols in the proposal – a *basic access* method that uses two-way handshaking (DATA-ACK) and a RTS/CTS variant that uses request-to-send and clear-to-send messages in a four-way handshake (RTS-CTS-DATA-ACK). This paper analyzes the former but not the latter, for two reasons: (1) the basic access method is mandatory, whereas RTS/CTS is an optional variant; (2) the performance for RTS/CTS is significantly different from that for basic access [2], and therefore requires a separate analytic model. We also do not discuss the no-ACK option meant for broadcasts and multicasts, nor the *point coordination function*, which is an optional polling scheme defined on top of basic access.

Basic access uses carrier-sensing multiple access with collision avoidance (CSMA/CA). There are numerous CSMA protocols, and their performance under low load conditions are usually similar [22,24]. The many variations arise because of efforts to improve on performance and push back the limits. Our analysis therefore focuses on the most important such limit – namely, the maximum (or saturation) throughput, which measures the capacity when the protocol is used to access the channel, and which is lower than the raw bandwidth for the physical medium itself.

Our model considers the case where multiple stations use the protocol to share a wireless channel without a coordinating base station. It assumes that the stations are homogeneous in traffic generation, channel noise is negligible, and there are no hidden terminals. A scenario that may fit these assumptions would be a classroom or meeting in which students or executives exchange information on their laptops. From the modeling perspective, it is not difficult (but somewhat tedious) to take noise into consideration; also, hidden terminals require a separate model and, in any case, should be analyzed together with RTS/CTS because the two are closely related [2,3,7].

In contrast to previous simulation studies of the 802.11 MAC protocols [2,13,23], the performance analysis we present here is based on a mathematical model. This model not only differs from previous analytic models of the 802.11 protocols [3,6,7,10], it is also different from the other techniques in the CSMA literature [1,5,12,14,15,17–20]. Whereas these studies use stochastic analysis (e.g., Markov chains), our model uses the average value for a variable wherever possible – this is a methodology that is commonly used in the performance analysis of computer systems. This technique is simple, yet effective: It provides closed-form expressions for the probability of a collision and the saturation throughput, thus facilitating the analysis of various issues, such as the choice of window size, the limit on the number of stations, and the tradeoff between collisions and backoffs. It also yields two rules of thumb: halving the initial window size W (for the exponential backoff) is similar in effect to doubling the number of stations, and the optimum choice of W is proportional to the square root of packet size.

A performance model is usually validated by comparing its numerical predictions with simulation results. For our