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Performance analysis under finite load and improvements for multirate 802.11

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Abstract

Automatic rate adaptation in Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) wireless networks may cause drastic throughput degradation for high-speed bit rate stations (STAs). The CSMA/CA medium access method guarantees equal long-term channel access probability to all hosts when they are saturated. In previous work it has been shown that the saturation throughput of any STA is limited by the saturation throughput of the STA with the lowest bit rate in the same infrastructure. In order to overcome this problem, we first introduce in this article a new model for finite load sources with multirate capabilities. We use our model to investigate the throughput degradation outside and inside the saturation regime. We define a new fairness index based on the channel occupation time to have more suitable definition of fairness in multirate environments. Further, we propose two simple but powerful mechanisms to partly bypass the observed decline in performance and meet the proposed fairness. Finally we use our model for finite load sources to evaluate our proposed mechanisms in terms of total throughput and Medium Access Control layer delay for various network configurations.

Keywords: IEEE 802.11b; Wireless LAN; Stochastic processes; Queueing theory; Network measurements

1. Introduction

In recent years, the IEEE 802.11b protocol for wireless LAN (WLAN) has become very popular as an access scheme for wireless and mobile Internet users. Access Points (APs) can be deployed wherever service customers need fast and mobile access to information. Such environments can be an airport, a campus, or a business building. The IEEE 802.11b standard specifies the Medium Access Control (MAC) layer, as well as the physical (PHY) layer. Currently, for the MAC layer, the standard defines two medium access coordination functions: the contention-based Distributed Coordination Function (DCF) and the contention-free based Point Coordination Function (PCF) [1]. In this article we consider only the DCF access method. The PCF access method is not mandatory and, therefore, is rarely implemented in current 802.11b products.

The DCF access method is based on the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) principle. Each STA has the same priority when competing for an empty slot time, which guarantees long-term fairness in access probability. Before an STA attempts a *first* packet transmission, it has to sense the medium. If the medium is found idle for a minimum time equal to the Distributed Inter Frame Space (DIFS), the packet will be transmitted directly. Otherwise, the STA enters into backoff and randomly sets its backoff timer within the range of the Contention Window (CW). The backoff timer is decremented by one every slot time when medium is sensed idle and it is frozen when medium is sensed busy. When it reaches zero, the STA starts the next transmission. Upon the correct receipt of a packet, the receiver has to send an acknowledgment (ACK) after

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a time equal to the Short Inter Frame Space (SIFS). If no ACK is received, the sending STA assumes a collision, doubles its current CW, randomly resets its backoff timer, and retransmits the packet when the timer reaches again zero.

The IEEE 802.11b specifications for the PHY layer support multirate adaptation and allow channel bit rates up to 11 Mbps. As in any wireless communication system, bit errors due to noise and interference from the Industrial Science–Medical (ISM) band are of fundamental concern. High bit error rates in wireless environments require not only sophisticated channel coding but also control over the channel modulation rate. It is well known that a decrease in the symbol period increases the probability of an incorrect detection. The 802.11b standard tackles this problem by offering four different modulation rates. The mechanism, which is implemented in current 802.11b products, counts the number of unsuccessful frame transmissions and reduces its channel bit rate accordingly from 11 Mbps to either 5.5, 2, or 1 Mbps. However, the standard does not consider the fact that packet transmission at 1 Mbps might take up to 11 times longer than an equal packet size transmission at 11 Mbps! The standard still guarantees all STAs the same long-term medium access probability. As a result, the medium underlies an overall unfair time allocation for STAs with different rates. This unfairness is especially reflected in the throughput of the STA with the highest bit rate, namely 11 Mbps. It has been proven in Ref. [3] that, if there are two different bit rates in the same environment, the saturation throughput of any STA will be equal to the saturation throughput of the STA with the lowest channel bit rate. For instance, this phenomenon can be seen in Fig. 1 where we measure the saturation throughputs of two STAs, one fixed STA close to the AP and transmitting all of the time at its maximum rate 11 Mbps, and another STA moving around the AP whose transmission rate varies as indicated in the top figure. Both STAs have their sending queaes saturated with UDP packets of payload size equal to 1470 bytes. The bottom figure shows the saturation throughput of both STAs averaged over 1-s time intervals. We notice how the saturation throughput of the fixed STA follows that of the moving STA even though the close STA has an excellent wireless connection to the AP and always has data frames to transmit.

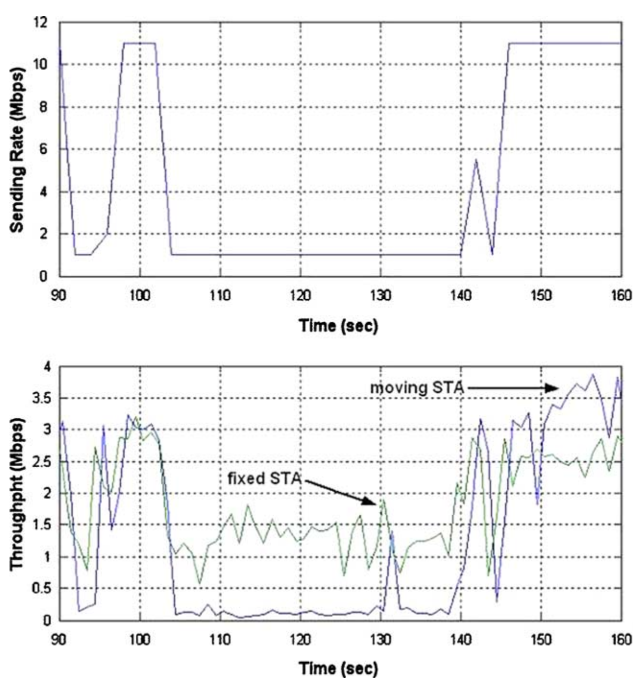

Fig. 1. The throughput of one fixed STA and one moving STA.

This performance anomaly of IEEE 802.11b has been analyzed in Ref. [3] using a simplified model and assuming saturated sources, further no solutions are proposed in Ref. [3]. A saturated source is defined as an STA always having packets to send in its queue. In Ref. [6] the complex behavior of 802.11b protocol is analyzed with Markov chains, assuming one single modulation rate and saturated sources.

In our real 802.11b testbed we conduct experiments which show that the throughput degradation faced by high-rate STAs strongly depends on how loaded the low-rate STAs are. This explains the need for a model considering non-saturated as well as saturated sources. An analytical model for non-saturated sources is proposed in Ref. [4] based on Ref. [6], however, the assumptions only hold for very low traffic load. Although an infinite MAC buffer is considered, the model in Ref. [4] discards all packets in the buffer after the first packet has been taken by the DCF. In Ref. [5], a different approach is taken to analyze the performance under statistical traffic. The on–off characteristics of the STAs are modelled with a state-dependent single server queue where the service time for the different states are estimated from the saturation throughput obtained in Ref. [6]. This model assumes equal service time and equal packet sending rates for all participating STAs and, therefore, cannot be applied to multirate environments. Moreover, the model in Ref. [5] is not very accurate in modelling finite-load scenarios since it supposes that an STA reaches directly its saturation throughput, which is not acceptable if the active time of an STA is comparable to the transitory regime duration. All this motivates us to develop a model for finite load sources with a MAC buffer for multirate environments. We explain in this article the model for the case of two bit rates. Its extension to more than two bit rates is a straightforward exercise that we omit for lack of space. Note that we present at the end of the article some analytical results for the case of three bit rates. Clearly our model for non saturated STAs in multirate environments can be specified to the case of one bit rate, which in itself is an important finding.

We analyze the fairness problem of 802.11b in multirate environments using our model and real experiments. The observed performance anomaly drives the need for a different fairness metric. Thus, we propose a new fairness index giving equal channel occupation time to all STAs. We provide two solutions (optimal minimum CW and optimal