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ITB12586

This paper appears in the book, *Emerging Trends and Challenges in Information Technology Management, Volume 1 and Volume 2* edited by Mehdi Khosrow-Pour © 2006, Idea Group Inc.

Performance Study of IEEE 802.11b Wireless LAN under High Traffic Conditions

Nurul I. Sarkar, School of Computer & Information Sciences, Auckland University of Technology, Private Bag 92006
Auckland 1020, New Zealand, P +64 9 9219999, F +64 9 9219944, nurul.sarkar@aut.ac.nz

ABSTRACT
The IEEE 802.11b medium access control (MAC) protocol is gaining widespread popularity as a layer-2 protocol for wireless local area networks (WLANs). A good MAC protocol for WLANs should provide an efficient mechanism to share a limited wireless channel bandwidth, together with high bandwidth utilization and fairness in serving all stations. In this paper we study the performance of IEEE 802.11b WLAN under high traffic load conditions by simulation. We examine the effect of active stations on network throughput, mean delay and fairness performance especially at medium-to-high traffic loads under both ad hoc and infrastructure networks. Results show that the IEEE 802.11b protocol does not perform well in terms of providing high throughput, low mean delay and good fairness at medium-to-high traffic load conditions, and therefore the protocol requires an improvement.

INTRODUCTION
IEEE 802.11b-based MAC protocols are gaining widespread popularity as a layer-2 protocol for WLANs. This popularity is because of the simplicity in operation, low cost, robustness, and user mobility offered by the technology.

A good medium access control (MAC) protocol for WLANs should provide an efficient mechanism for sharing a limited wireless channel bandwidth, together with simplicity of operation, fairness in serving all stations, and high bandwidth utilization. Ideally low mean delay, high throughput and a good degree of fairness under high traffic load conditions is desired, but in reality it is usually very difficult to satisfy all the quality of service (QoS) provisions simultaneously. Therefore, a variety of MAC protocols have been proposed to suit different applications, where various tradeoff factors have been considered (Kwon, Fang, & Latchman, 2003; Natkaniec & Pach, 2002; Obaidat & Green, 2004; Xiao, 2004; Yin & Leung, 2005).

Detailed discussion of IEEE 802.11-based WLANs can be found in the wireless networking literature (1999; Bianchi, 2000; Tickoo & Sikdar, 2003; Xu, Gerla, & Bae, 2002). Cali et. al (2000) proposed an enhancement to the IEEE 802.11 protocol called Dynamic IEEE 802.11, which is basically a distributed algorithm for altering the size of the backoff window. Bruno and Conti (2002) analyzed the performance of p-persistent IEEE 802.11. Instead of the binary exponential backoff used in the original IEEE 802.11 protocol, the backoff interval of the p-persistent IEEE 802.11 is sampled from a geometric distribution with a parameter *p*. Cesana *et. al* (2003) investigated a new scheme called Interference Aware MAC (IA-MAC) to improve the performance of IEEE 802.11 in environments with high interference levels. Richard Lin and Liu (2002) proposed a scheme called Distributed Cycle Stealing (DCS) to enhance the performance of IEEE 802.11 by applying power control and spatial reuse.

To alleviate the fairness problem of IEEE 802.11, there have been many performance studies reported in the literature (Bharghavan, 1994; Ozugur, 2002; Wang, Ye, & Tseng, 2005).

While many innovative MAC protocols have been developed recently, the problem of efficient channel utilization, higher throughput, lower mean delay and fairness has not been fully solved yet. A study on the performance of IEEE 802.11b protocol under high traffic load conditions is required to assist efficient MAC protocol design for WLANs to achieve a better QoS in such systems.

The remainder of this paper is organized as follows. We first provide an overview of IEEE 802.11 protocol and then describe a simulation model for performance study of the IEEE 802.11b. The performance of IEEE 802.11b is examined, and a brief conclusion ends the paper.

OVERVIEW OF IEEE 802.11 WLAN
The IEEE 802.11 standard covers both physical and MAC layer of open system interconnections (OSI) model (Anonymous, 1999). The standard specifies that a network can be configured in two different ways: (1) ad hoc; and (2) infrastructure. In an ad hoc network, computers are brought together to form a network dynamically. There is no definite structure and any two computers can communicate as long as they are within the 'hearing' range from each other. In an infrastructure network, mobile stations communicate through an access point linked to the wired backbone network.

IEEE 802.11 MAC layer coordinates wireless channel access among the active stations on the network. This coordination is implemented using a distributed coordination function (DCF) and a point coordination function (PCF). We consider the DCF mode in IEEE 802.11 which has been widely deployed because of its simplicity and robustness. IEEE 802.11 adopts a carrier sense multiple access with collision avoidance (CSMA/CA) protocol, which requires every station to perform carrier sensing to determine the current state of the channel (i.e., idle or busy).

Figure 1 illustrates the basic operation of IEEE 802.11 DCF protocol. A station with a packet to transmit monitors the channel activities until an idle period equal to a DCF inter-frame space (DIFS) is detected. After sensing an idle DIFS, the station waits for a random backoff interval before transmitting. The collision avoidance mechanism adopted in the IEEE 802.11 standard is based on a binary exponential backoff scheme, which is implemented by each station by means of a parameter known as the backoff counter.

The backoff time is used to initialize the backoff counter. This counter is decreased only when the medium is idle and is frozen when activity is sensed. The backoff counter is periodically decremented by one slot time each time the medium sensed is idle for a period longer than a DIFS. A

Figure 1. Basic operation of IEEE 802.11 DCF

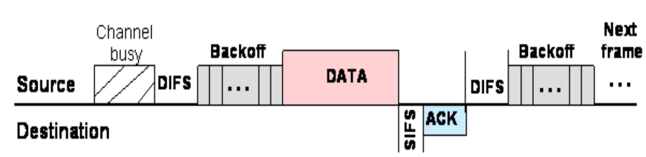


Table 1. Parameters used in simulation

Parameter	***Values***
Bandwidth	11 Mbps
Basic Rate	2 Mbps
SIFS	10 µs
DIFS	50 µs
Slot time	20 µs
Traffic type	UDP
Application	CBR
RTS/CTS	Off
PHY modulation	DSSS
CWmin	31
CWmax	1023
Simulation time	50 seconds

station transmits a packet when its backoff counter is zero. A detailed description of the IEEE 802.11 backoff algorithm can be found in (Anonymous, 1999; Tickoo & Sikdar, 2003).

SIMULATION MODEL OF IEEE 802.11

A simulation model has been developed using the ns-2 simulator (Fall & Varadhan, 2003) to study the throughput, mean delay, and fairness performance of the IEEE 802.11b DCF protocol.

Modeling Assumptions and Configuration

To simplify the simulation model, we consider a perfect radio propagation environment in which there is no transmission error due to interference and noise on the system, and no hidden and exposed station problems. The following assumptions are made regarding the data traffic:

A1. **Packet Generation:** Streams of data packets arriving at stations are modeled as independent Poisson processes with an aggregate mean packet generating rate » packets/s.

A2. **Packet Size**: Packets are of fixed length. The time axis is divided into slots of equal length, and the transmission of one packet takes one slot time.

A3. **Buffer size**: Each station in the network has a large buffer, modeled as a buffer of infinite size, to store packets. This assumption means that packets cannot be lost due to a buffer overflow when the system is under manageable input loads.

A4. **Destination addresses**: We assume that a packet arrives at a station are uniformly destined to $N - 1$ other stations in the network.

A5. **Stations spacing:** The stations can be arbitrarily spaced on the network within the transmission range.

A6. **Analysis:** We study the network performance under steady-state conditions.

Table 1 lists the parameter values that we used in the simulation. Each simulation run lasts for 50 seconds simulated time, in which the first 10 seconds is the transient period. The observations collected during transient period are not included in the final simulation results.

Model Validation

The models built using ns-2 simulator were validated using empirical measurements from wireless laptops and access points for an IEEE 802.11b wireless LAN (Sarkar, 2005). A good match between ns-2 simulation results and empirical measurements validates our simulation models. We have also compared our simulation results with the work of others (Nicopoliditis, 2003). The experimental results of the IEEE 802.11b protocol are discussed next.

RESULTS

We consider three important network performance metrics: (1) throughput; (2) mean packet delay; and (3) fairness, for both individual stations and the overall network. The throughput (measured in Mbps) is defined as the fraction of the total channel capacity that is used for data transmission. The mean packet delay at station $i(i = 1, 2, \cdots, N)$ is defined as the average time (measured in seconds) from the moment the packet is generated until the packet is fully despatched from that station. A packet arriving at station i experiences several components of delay including queuing delay, channel access delay (i.e., contention time) and packet transmission time.

Fairness in channel access might mean that all active stations on the network have an equal opportunity in accessing a shared wireless channel for packet transmission. We define a new metric for fairness measurement called 'mean deviation of bandwidth (MDB)' as follows:

$$MDB = \frac{\sum \left(B_i - \overline{B}\right)}{N} \tag{1}$$

Where Bi is the bandwidth at station i; $\overline{B}$ is the mean bandwidth of the network; and N is the number of active stations on the network.

As seen in Equation (1), MDB is defined as the spread or variation of an individual station's bandwidth from the network mean bandwidth. For instance, a MAC protocol is said to be 100% fair if the MDB is zero (i.e. Bi = $\overline{B}$). The non-zero MDB indicates the level of unfairness of a MAC protocol. Certainly, a MAC protocol with smaller MDB is preferred. We use MDB for studying the fairness performance of IEEE 802.11b protocol.

In this section, we present the experimental results obtained from simulation runs for the IEEE 802.11b. We examine the performance of the IEEE 802.11b by considering both ad hoc and infrastructure networks with user datagram (UDP) traffic operating under uniform loads (in which the packet arrival rate is same for all stations). We consider Poisson packet arrivals and a packet length of 1,500 bytes (a realistic figure close to the wired Ethernet protocol). The simulation results report the steady-state behavior of the network and have been obtained with the relative error less than 5%, at the 95% confidence interval.

Effect of active stations on network throughput performance: In Fig. 2, we plot network throughput versus number of active stations for both ad hoc and infrastructure networks. We observe that the network throughput decreases as we increase the number of active stations for N = 1 to 80 stations at 80% offered load. We also observe that the network throughput under the infrastructure network is slightly smaller than the ad hoc network, especially for N > 30 stations. Under both the ad hoc and infrastructure networks, the throughput is saturated at around N ≥ 80 stations.

Now let us examine the maximum and minimum throughput of the IEEE 802.11b. As seen in Fig. 2, the maximum achievable throughput is 4.4 Mbps for N = 1 station at 80% offered load. This throughput is around 40% of the maximum theoretical bandwidth of 11 Mbps. The minimum throughput under the infrastructure network is 1.7 Mbps which is around 15.6% of the maximum bandwidth of 11 Mbps for N= 70 stations at 80% offered load. However, the minimum throughput under the ad hoc network is 2.9 Mbps (i.e. 26.4% of the maximum bandwidth of 11 Mbps) for N= 80 stations at 80% offered load.

Throughput performance of selected stations: In this experiment we consider an IEEE 802.11b infrastructure network with N = 1, 5, 10, 20 and 40 stations. As seen in Fig. 3 the throughput performance of the IEEE 802.11b decreases significantly as we increase the number of active stations on the network, especially for N = 10 to 40 stations. We observe that the throughput increases sharply with increasing offered load from 10 to 40%. For the offered load greater than 40%, the increase in throughput is not very significant.

The main conclusion we can draw from Figs. 2 and 3 is that the network throughput performance under the IEEE 802.11b WLAN deteriorates

Figure 2. Effect of active stations on network throughput performance of IEEE 802.11b networks

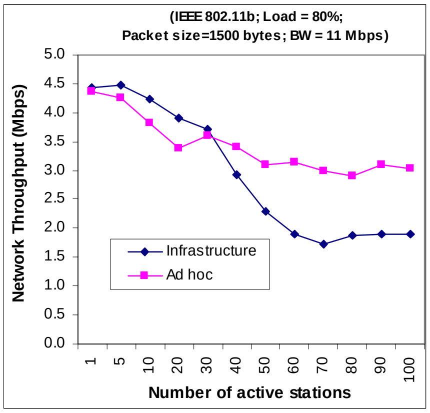


Figure 3. Effect of increasing number of active stations on network throughput performance of IEEE 802.11b infrastructure network

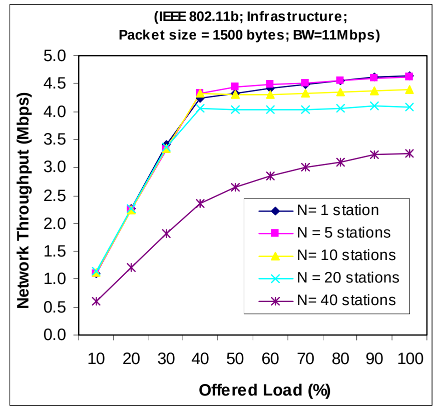


Figure 5. Effect of increasing number of active stations on fairness performance of IEEE 802.11b (Load = 80%)

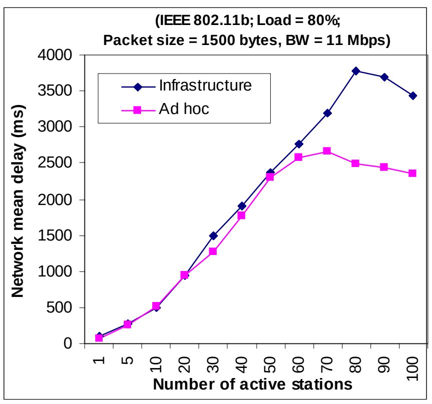
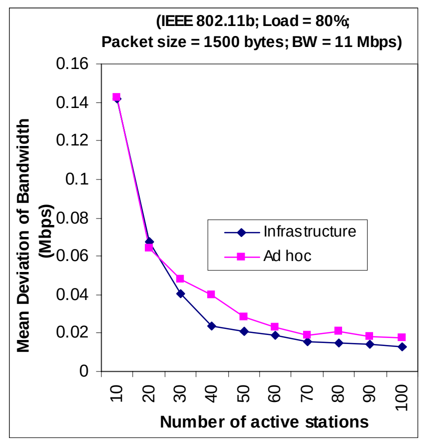


Figure 4. Network mean packet delay versus number of active stations of IEEE 802.11b (Load = 80%)



for N > 10 stations, especially at medium-to-high offered loads. This throughput deterioration is due to the wastage of transmission capacity in the backoff state of IEEE 802.11b protocol.

Effect of active stations on network mean delay performance: In Fig. 4, we plot network mean packet delay versus number of active stations for both ad hoc and infrastructure networks.

We observe that under both the ad hoc and infrastructure networks, the mean packet delay increases as we increase the number of active stations for N = 1 to 70 stations for ad hoc, and for N = 1 to 80 stations for infrastructure network, both operating at 80% offered load. We also observe that mean packet delay under the ad hoc network is slightly better (i.e. smaller delay) than the infrastructure network, especially for N > 20 stations.

The main conclusion we can draw from Fig. 4 is that the network mean packet delay performance under the IEEE 802.11b WLAN deteriorates as we increase the number of active stations on the network, especially at high offered load. Therefore, the IEEE 802.11b WLAN may not be a suitable candidate for real-time applications (e.g. multimedia communication) because the mean packet delay is very large for N e•20 stations at high offered loads.

Effect of active stations on network fairness performance: The effect of active stations on network fairness performance under both the ad hoc and infrastructure networks is shown in Fig. 5.

We observe that the IEEE 802.11b does not provide 100% fairness in allocating channel bandwidth among the active stations on the network at 80% offered load. This unfairness is due to the wastage of transmission bandwidth in the backoff state of IEEE 802.11b. We also observe that the infrastructure network provides slightly better fairness (i.e., up to 41% lower MDB) than the ad hoc network for N = 40 stations at 80% traffic load.

The main conclusion we can draw from Fig 5 is that stations under the IEEE 802.11b protocol suffer unfairness in channel access, especially at high offered loads.

DISCUSSION AND CONCLUSION

In this paper we examined the throughput, mean delay and fairness performance of IEEE 802.11b WLAN by simulation. Results show that the IEEE 802.11b does not perform well in terms high throughput, low mean delay, and good fairness at medium-to-high traffic load conditions. For example, if the number of active users increases, both mean delay and throughput performance of the IEEE 802.11b protocol degrades significantly. In addition, the IEEE 802.11 protocol does not provide a good degree of fairness in allocating channel bandwidth among the active stations on the network especially at high traffic loads.

Using simulation experiments we gained an insight into the performance of IEEE 802.11b WLANs under high traffic load conditions. Clearly, the existing IEEE 802.11b WLANs cannot be used for high bandwidth real-time applications serving large number of users. Therefore, to achieve an optimum network performance the IEEE 802.11b WLAN requires an improvement.

Although various enhancements to the original IEEE 802.11 protocol have been proposed recently, the problem of efficient channel utilization, higher throughput, lower mean delay and good fairness has not been fully solved yet. More research is needed in the areas of MAC protocol design and performance improvement of IEEE 802.11b-based WLANs. The joint MAC-physical layer design approach for performance improvement of the IEEE 802.11b is planned as an extension of the present study.

The models built using ns-2 simulator were validated using empirical measurements from wireless laptops and access points for an IEEE 802.11b WLAN. A good match between simulation results and empirical measurements is reported.

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