Performance Analysis of IEEE 802.11 MAC and Physical Layer on Saturation Throughput

B. Manikyala Rao, P. N. S. Lakshmi

Abstract*— An analytical model that accounts for the positions of stations with respect to the Access Point (AP) while evaluating the performance of 802.11 MAC layer. This paper is based on the Bianchi's model where the performance of 802.11 MAC layer is computed using a discrete time Markov chain, but where all stations are implicitly assumed to be located at the same distance to the AP. In this model, given the position of one station, we compute its saturation throughput while conditioning on the positions of the other concurrent stations. Further, this model provides the total saturation throughput of the medium and describe the model numerically and show that the saturation throughput per station is strongly dependent not only on the station's position but also on the positions of the other stations, and confirm that a station achieves a higher throughput when it is closer to the AP but bring out that there is a distance threshold above which the throughput decrease is fast and significant. When a station is far from the AP compared to the other stations, it will end up by contending for the bandwidth not used by the other stations. This model is a good tool to dimension 802.11 wireless access networks and to study their capacities and their performances.

***Index Terms*—MAC Layer, Access point, throughput.**

I. INTRODUCTION

The modeling of the 802.11 MAC layer is an important issue for the evolution of this technology. The existing models for 802.11 assume that all shared among all stations (STAs) have the same physical conditions at the receiving STA (same power, same coding...), so when two or more STAs emit a packet in the same slot time, all their packets are lost, which may not be the case in reality when for instance one STA is close to the receiving STA and the other STAs far from it. This behavior, called the *capture effect*, can be analyzed by considering the spatial positions of the STAs. In the spatial positions of STAs are considered for the purpose of computing the capacity of wireless networks.

II. BACKGROUND

2.1 CSMA/CA with RTS/CTS exchange

Two forms of MAC layer have been defined in IEEE 802.11 standard specification named, Distributed Coordination Function (DCF) and Point Coordination Function (PCF). The DCF protocol [2] uses Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) mechanism and is mandatory, while PCF is defined as an option to support time-bounded delivery of data frames. The DCF protocol in IEEE 802.11 standard defines how the medium is shared among stations. DCF which is based on CSMA/CA, consists of a basic access method and an optional channel access method with request-to-send (RTS) and clear-to-send (CTS) exchanged as shown in Fig. 1.

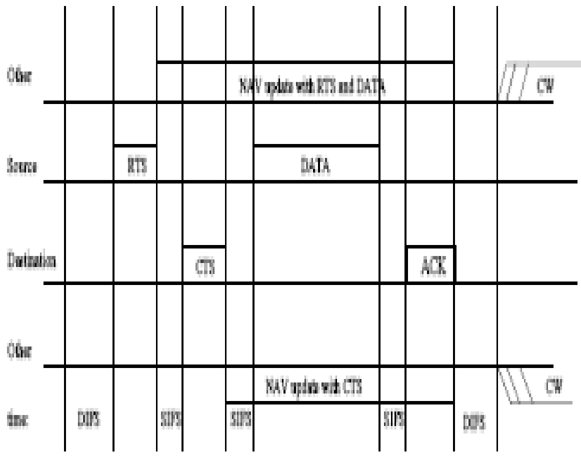

Figure 1. CSMA/CA with RTS/CTS exchange.

If the channel is busy for the source STA, a back off time (measured in slot times) is chosen randomly in the interval (0*; CW*), where CW is called the contention window. This timer is decremented by one as long as the channel is sensed idle for a DIFS (Distributed Inter Frame Space) time. It stops when the channel is busy and resumes when the channel is idle again for at least DIFS time. *CW* is an integer with the range determined by PHY layer characteristics: *CW min* and *CW max*. *CW* will be doubled after each unsuccessful transmission, up to the maximum value which is determined by *CW max* + 1. When the back off timer reaches zero, the source transmits the data packet. The ACK is transmitted by the receiver immediately after a period of time called SIFS (Short Inter Frame Space) which is less than DIFS. When a data packet is transmitted, all other stations hearing this transmission adjust their Network Allocation Vector (NAV), which is used for virtual CS at the MAC layer.

In optional RTS/CTS access method, an RTS frame should be transmitted by the source and the destination should accept the data transmission by sending a CTS frame prior to the transmission of actual data packet.

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Note that STA's in the sender's range that hear the RTS packet update their NAVs and defer their transmissions for the duration specified by the RTS.

Nodes that overhear the CTS packet update their NAVs and refrain from transmitting. This way, the transmission of data packet and its corresponding ACK can proceed without interference from other nodes (hidden nodes problem).

III. OVERVIEW OF MEDIUM ACCESS LAYER

The original IEEE 802.11 standard specifies the physical layer and the medium access layer mechanisms and provides a data rate up to 2 Mbps. Further the standards IEEE 802.11b modifies the physical layer part of the standard and increases the maximum data rates to 11 Mbps and 54 Mbps respectively. In this paper as I have discussed the basic 802.11 MAC layer functionality called Distributed Coordination Function (DCF) for distributed access to the shared medium.

3.1 IEEE 802.11 Physical Layer

One of the fundamental challenges in wireless networks is the continuously changing physical layer properties of the channel. The physical layer of 802.11b can support multiple data rates. Depending on the channel quality the data rate can be altered to keep the bit error rate acceptable, as high data rates are also prone to high bit error rates. The 802.11b standard operates in the 2.4 GHz band and supports 1, 2, 5.5 and 11 Mbps.

Table.1 shows the main characteristics of the IEEE 802.11a/b/g physical layers. 802.11b radios transmit at 2*:*4*GHz* and send data up to 11 Mbps using Direct Sequence Spread Spectrum (DSSS) modulation; whereas 802.11a radios transmit at 5*GHz* and send data up to 54 Mbps using Orthogonal Frequency Division Multiplexing (OFDM). The IEEE 802.11g standard extends the data rate of the IEEE 802.11b to 54 Mbps in an upgraded PHY layer named extended rate PHY layer.

Table 1. PHY Layer Characteristics in 802.11

PHY Layer Characteristic	Available in 802.11/a/b/g
Frequency	5,2.4 GHz
Data Rates	1,2,5.5,6,9,11,12,18,22,24,33,36,48,54 Mbps
Modulation	BPSK, DBPSK, QPSK, DQPSK, 16-QAM, 64-QAM, CCK
Error Correction Code	Convolutional codes 1/2, 2/3, 3/4

In each physical layer, there is a basic transmission mode (usually used to send ACK, RTS, CTS and PLCP header) which has the maximum coverage range among all transmission modes. This maximum range is obtained using BPSK or DBPSK modulation which have the minimum probability of bit error for a given SNR compared to other modulation schemes. It has the minimum data rate as well. As shown in Fig. 2, each packet may be sent using two different rates; the PLCP header is sent at the basic rate while the rest of the packet might be sent at a higher rate. The basic rate is 1 Mbps (with DBPSK modulation and CRC 16 bits) for 802.11b and 6 Mbps (with BPSK and FEC rate equal to 1/2) for 802.11a. The higher rate used to transmit the physical-layer payload (which includes the MAC header) is indicated in the PCLP header.

The PLCP Protocol Data Unit (PPDU) frame includes PLCP preamble, PLCP header, and MPDU. Fig. 3 shows the format for long preamble in 802.11b. The PLCP preamble contains the following fields: Synchronization (Sync) .

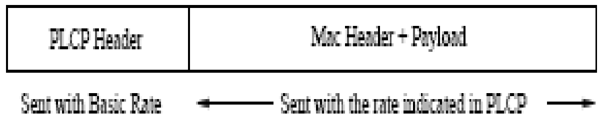

Figure 2. Packet format in IEEE 802.11.

and Start Frame Delimiter (SDF). The PLCP Header contains the following fields: Signal, Service, Length, and CRC. The short PLCP preamble and header may be used to minimize overhead and thus maximize the network data throughput. Note that the short PLCP header uses the 2 Mbps with DQPSK modulation and a transmitter using the short PLCP only can interoperate with the receivers which are capable of receiving this short PLCP format. In this paper we suppose that all stations use the long PPDU format in 802.11b. We evaluate our model in 802.11b where STAs use transmission rate equal to 1 and 2 Mbps. Our model can be employed for all other transmission modes for all standards if the packet error rate is calculated.

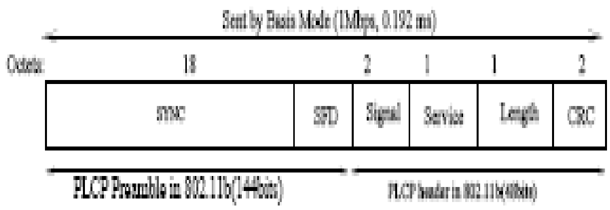

Figure 3. 802.11b long preamble frame format.

IV. NEED AND IMPORTANCE

Present days, the IEEE 802.11 WLAN technology offers the largest deployed wireless access to the Internet. This technology specifies both the Medium Access Control [1] (MAC) and the Physical Layers (PHY). The PHY layer selects the correct modulation scheme given the channel conditions and provides the necessary bandwidth, whereas the MAC layer decides in a distributed manner on how the offered bandwidth is shared among all stations (STAs). This standard allows the same MAC layer to operate on top of one of several PHY layers.

This model has different extensions on which we are working on. One extension considers an Access Point (AP) that transmits packets, which would allow finding the optimal Access Point placement for a given topology.

There have been various attempts to model and analyze the saturation throughput and delay of the IEEE 802.11 MAC layer [6].

V. OBJECTIVES

Therefore, my Research work mainly aims at computing the saturation throughput of the MAC layer and focus on its improvement.

The present study is conducted to observe both PHY and MAC layer protocols to analyze the performance of exciting IEEE 802.11 standard [3]. The Two forms of MAC layer have been defined in IEEE 802.11 standard specification named, Distributed Coordination Function (DCF) and Point Coordination Function (PCF). The DCF protocol [8] user Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) mechanism and is mandatory, while PCF is defined as an option to support time bounded delivery of data frames. The DCF protocol in IEEE 802.11 standard defines how the medium is shared among stations. DCF which is based on CSMA/CA consists of a basic access method and an optional channel method with request-to-send and clear-to-send (CTS).

VI. RELATED WORK

There have been various attempts to model and analyze the saturation throughput and delay of the IEEE 802.11 DCF protocol since the standards have been proposed. As explained in the introduction there are different analytical models and simulation studies that analyze the performance of 802.11 MAC layer. Since this model we have used the Bianchi's model and its extension proposed. Bianchi's model uses a simple and elegant discrete-time Markov chain to analyze the case of saturated STAs, i.e. STAs that always have packets to send. The proposed scheme named *DCF+* to enhance the performance of reliable transport protocol [4] over WLAN and analyzed it with an extension of Bianchi's considering finite packet retry limits as defined in the IEEE 802.11 standard [5].

The retransmission limit is defined in the IEEE 802.11 MAC standard specification with the help of two following counters: Short Retry Count (SRC) and Long Retry Count (LRC). These counters are incremented and reset independently. SRC is incremented every time an RTS fails and LRC is incremented when data transmission fails. Both SRC and LRC are reset to zero after a successful data transmission. Data frames are discarded when LRC (SRC) reaches dot11LongRetryLimit (dot11ShortRetryLimit). The default values for dot11LongRetryLimit and dot11ShortRetryLimit are 4 and 7 respectively.

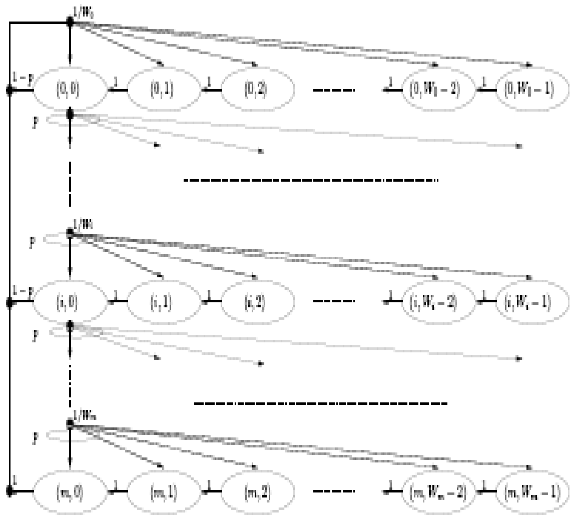

Figure 4. Markov model for backoff window.

VII. CONCLUSION

One of the most promising models has been the so-called Bianchi model. This model uses a simple and elegant discrete time Markov chain to analyze the case of saturated shared among all stations (STAs), STAs that always have packets to send. The scheme DCF is to enhance the performance of reliable transport protocol over WLAN, and analyzed it to further extension to consider finite packet retry limits as defined in the IEEE 802.11 standard. It provides closed form expressions for the saturation throughput and for the probability that a packet transmission fails due to collision. The future work can be solve this model numerically and show the saturation throughput [7] per station is strongly dependent not only on the station's position but also on the positions of the other stations.

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