Performance Analysis of IEEE 802.11 Non-Saturated DCF

Bhanu Prakash Battula[1] ,R.Satya Prasad[2] and Mohammed Moulana[3]

[1]**Asst. Professor , Dept. of CSE, Vignan's Nirula Institute of Technology and Science for Women , A.P., India.**

[2]**Professor,Acharya Nagarjuna University,Dept.of Computer Science and Engineering. A.P,India.**

[3]**Asst. Professor , Dept. of CSE, Vignan's Nirula Institute of Technology and Science for Women , A.P. India.**

Abstract

In the IEEE 802.11MAC layer protocol, the basic access method is the Distributed Coordination Function which is based on the CSMA/CA. In this paper, we investigate the performance of IEEE 802.11 DCF in the non-saturation condition. We assume that there is a fixed number n of competing stations and packet arrival process to a station is a poisson process. We model IEEE 802.11 DCF in non-saturation mode by 3-dimensional Markov chain and derive the stationary distribution of the Markov chain by applying matrix analytic method. We obtain the probability generating function of packet service time and access delay, and throughput.

Keywords: *DCF, Access delay, throughput.*

1. Introduction

Recent years Wireless Local Area Networks have brought much interest to the telecommunication systems. IEEE 802.11 standards define a medium access control protocols. IEEE 802.11 MAC includes the mandatory contention-based DCF (Distributed Coordination Function) and the optional polling-based PCF (Point Coordination Function)[1]. Most of today's WLANs devices employ only the DCF because of its simplicity and efficiency for the data transmission process. The DCF employs CSMA/CA (Carrier-Sense Multiple Access with Collision Avoidance) protocol with binary exponential backoff. The DCF is relatively simple while it enables quick and cheap implementation, which is important for the wide penetration of a new technology.

We may classify arrival pattern of packets to the station into two modes: saturation mode and non-saturation mode. Saturation mode means that stations always have packets to transmit. Non-saturation mode means that stations have sometimes no packets to transmit. Most of analytical models proposed so far for the IEEE 802.11 DCF focus on saturation performance. Unfortunately, the saturation assumption is unlikely to be valid in most real IEEE 802.11 networks. We note that most works ignore the effect of the queue at the MAC layer. There have not been many analytic works in the non-saturation mode due to mainly analytic complexity of models. The necessities of analytic performance of IEEE 802.11 in non-saturation mode.

2. Overview of Medium Access Layer

Nowadays, the IEEE 802.11 WLAN technology offers the largest deployed wireless access to the Internet. This technology specifies both the Medium Access Control (MAC) and the Physical Layers (PHY) [1]. 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.

Different analytical models and simulation studies have been elaborated the last years to evaluate the 802.11 MAC layer performance. These studies mainly aim at computing the saturation throughput of the MAC layer and focus on its improvement. One of the most promising models has been the so-called Bianchi model [2]. It provides closed form expressions for the saturation throughput and for the probability that a packet transmission fails due to collision. The modeling of the 802.11 MAC layer is an important issue for the evolution of this technology. One of the major shortcomings in existing models is that the PHY layer conditions are not considered. The existing models for 802.11 assume that all 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 [3]. This behavior, called the *capture effect*, can be analyzed by considering the spatial positions of the STAs. In [4] the spatial positions of STAs are considered for the purpose of computing the capacity of wireless networks, but only an ideal model for the MAC layer issued from the information theory is used. The main contribution of this paper is considering both PHY and MAC layer protocols to analyze the performance of exciting IEEE 802.11 standard. Our work reuses the model for 802.11 MAC layer from [6], and extends it to consider interference from other STAs. We compute, for a given topology, the throughput of any wireless STA using the 802.11 MAC protocol with a specific PHY layer protocol. Without losing the generality of the approach, we only consider in this paper traffic flows sent from the mobile STAs in direction to the AP. The case of bidirectional traffic is a straight forward extension; we omit it to ease the exposition of our contribution. Further, we assume that all STAs use the Distributed Coordination Function (DCF) of 802.11 and they always have packets to send (case of saturated sources). We present an evaluation of our approach for 802.11b with data rates equal to 1 and 2 Mbps and the results indicate that it leads to very accurate results.

3. Importance Of Distributed Coordination Function (DCF)

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 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.

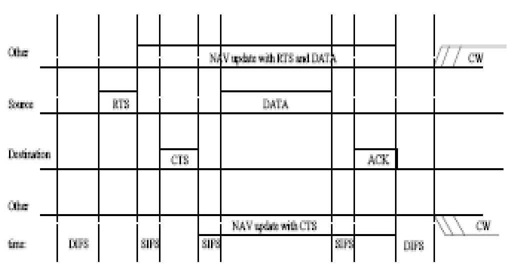

Figure 1. CSMA/CA with RTS/CTS exchange.

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: *CWmin* and *CWmax*. *CW* will be doubled after each unsuccessful transmission, up to the maximum value which is determined by *CWmax* + 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. Note that STAs 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).

Table 1 shows the main characteristics of the IEEE 802.11a/b/g physical layers. 802.11b radios transmit at 2:4GHz 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) [1]. The IEEE 802.11g standard [1], extends the data rate of the IEEE 802.11b to 54 Mbps in an upgraded PHY layer named extended rate PHY layer (ERP).

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

Table 1. PHY layer Characteristics in 802.11.

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 modulations 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)

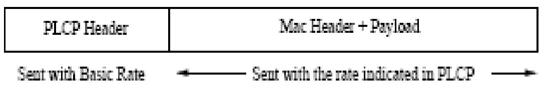

Figure 2. Packet format in IEEE 802.11.

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.

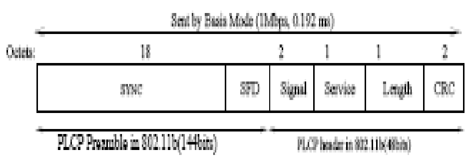

Figure 3. 802.11b long preamble frame format.

In this paper, we assume that the noise over the wireless channel is white Gaussian with spectral density equal to *N*0=2. In our model we define *N*0 as the power of the thermal noise,

$$N_o = N_f \,.\, N_t = N_f \,.\, kTW \qquad (1)$$

where *Nf* denotes the circuit noise value, *k* the Boltzmann constant, *T* the temperature in Kelvin and *W* is the frequency bandwidth. For the BPSK modulation1, the bit error probability is given:

$$P_b^{BPSK} = Q\left(\sqrt{2.\frac{Eb}{No}}\right) = Q\left(\sqrt{2.\frac{Eb}{No}}\right) \qquad (2)$$

and for QPSK (4-QAM) is:

$$P_b^{QPSK} = Q\left(\sqrt{2.\frac{Eb}{No}}\right) - \frac{1}{2}\, Q^2 \left(\sqrt{2.\frac{Eb}{No}}\right) \qquad (3)$$

4. Conclusion

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 is different analytical models and simulation studies that analyze the performance of 802.11 MAC layer. As an example Foh and Zuckerman present the analysis of the mean packet delay at different throughputs for IEEE 802.11 MAC. Kim and Hou analyze the protocol capacity of IEEE 802.11MAC with the assumption that the number of active stations having packets ready for transmission is large. They have suggested some extensions to the model proposed to evaluate packet delay, the packet drop probability and the packet drop time. Since in our model we have used the Bianchi's model and its extension proposed.

References

[1] Wireless LAN MAC and PHY layer specifications, LAN MAN Standards Committee of the IEEE Computer Society Std., ANSI/IEEE 802.11, 1999.

[2] E. Winands, T.Denteneer, J.Resing, and R. Rietman, "A finite-source feedback queueing network as a model for the IEEE 802.11 DCF", in European Transactions On Telecommunications, Vol 16, 2005, pp. 77-89.

[3] LI BO and Roberto Battiti, "Performance analysis of an Enhanced IEEE 802.11 Distributed Coordination Function Supporting Service Differentiation", in International Workshop on Quality of Future Intenet Service QoFIS 2003, Sweden, Spinger Lecture Notes on Computer Science LNCS volume 2811, 2004, pp. 152-161.

[4] LI BO and Roberto Battiti, "Achiving Maximum Throughput and Service Differentiation by Enhancing the IEEE 802.11 MAC Protocol", in WONS 2004, Springer Lecture Notes on Computer Science, Vol. 2928, pp. 285-301.

[5] IEEE 802.11 WG, part 11a/11b/11g , "Wireless LAN Medium Access Control (MAC) and Physical (PHY) specifications,", Standard Specification, IEEE, 1999.

[6] Giuseppe Bianchi, "Performance Anaylsis of the IEEE 802.11 Distributed Coordination Function", IEEE Journal on Selected Areas in Communications, Vol. 18, Number 3, March 2000.

[7] A. Kochut, A. Vasan, A. U. Shankar, A. Agrawala, ”Sniffing out the correct Physical Layer Capture model in 802.11b”, Proceeding of ICNP 2004, Berlin, Oct. 2004.
[8] P. Gupta, P. R. Kumar ” The Capacity of Wireless Networks”, IEEE Transactions on Information Theory, Vol. 46, No. 2, March 2000.
[9] C. H. Foh, M. Zukerman, “Performance Analysis of the IEEE 802.11 MAC Protocol”, Proceedings of the EW 2002 Conference, Italy.
[10] H. Wu, Y. Peng, K. Long, J. Ma, “Performance of Reliable Transport Protocol over IEEE 802.11 Wireless LAN: Analysis and Enhancement”, Proc. of IEEE INFOCOM, vol.2, pp. 599-607, 2002.

Authors profile

Bhanu Prakash Battula received Master’s Engineering degree on Computer Science & Technology in 2008 from Acharya Nagarjuna University and also received another Master’s degree on Computer Applications from Acharya Nagarjuna University. After Post graduation, He is working as a Asst.Professor in the Department of Computer Science and Engineering at Vignan’s Nirula Institute of Technology and Science, Guntur, Andhra Pradesh. He published papers for International Journals. His research interests include Computer Security, Steganalysis and Image Processing.

R.Satya Prasad received PhD from Acharya Nagarjuna University in 2007. He is working as a Professor at Department of Science and Engineering, Acharya Nagarjuna University. He Published more than 15 National and International publications and his research interests include Computer Security, Software reliability and Image Processing

Mohammed Moulana received the Master's degree M.Sc Mathematics from Acharya Nagarjuna University, in 2004. He received M.Phil in Mathematics from Alagappa University in 2007. He received M.Tech Computer Science & Engineering in 2009 from JNTUK, Kakinada, A.P., India. He is currently an Asst. Professor, Department of Computer Science & Engineering, Vignan's Nirula Institute of Technology and Science for Women, Guntur Dist, A.P., India. His Area of Interest are Communication Networks, Wireless LANs & Ad-Hoc Networks.

.