SATURATION AND NON-SATURATION THROUGHPUT AND PACKET DELAY ANALYSIS OF IEEE 802.11 DCF FOR AD-HOC NETWORKS

D Laxma Reddy, K Nishanth Rao, A.V.Paramkusam
Department of Electronics and Communication Engineering,
MLR Institute of Technology, Telangana, India

K Nehru
Department of Electronics and Communication Engineering,
MLR Institute of Technology, Telangana, India

ABSTRACT
A wireless LAN is a data transmission system. This paper presents an analytic model to evaluate the throughput and delay performance of AFR over noisy channels. In comparatively to other models, our model reaches the more accurate. The Analytical and simulation analysis models are developed to estimate the throughput and delay performance of AFR over a noisy channel.

Key words: Ad-hoc Networks, IEEE 802.11, PCF, DCF, AFR, Collision and Transmission Portability.

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1. INTRODUCTION
An ad hoc mode, the mobile units transmit directly peer-to-peer, it does not rely on a pre-existing communications, such as routers in wired networks or access points in managed (infrastructure) wireless networks. The wireless local area network (WLAN) protocol, the IEEE 802.11, and many more associated technologies, such as the 802.1X protocol and it is Wi-Fi Protected Access (WPA), allow secure high-speed wireless network access.

802.11b uses the same unregulated radio signaling frequency (2.4 GHz) using either direct sequence spread spectrum (DSSS) or frequency hopping spread spectrum (FHSS)[1][2]. In most of the WLAN products based on the IEEE 802.11b protocol the transmitter is designed as a Direct Sequence Spread Spectrum Phase Shift Keying (DSSS PSK) modulator, which is capable of handling data rates of up to 1Mbps -11Mbps [5].
In communication networks, throughput or network throughput is the average rate of successful data delivery over a communication channel. This data may be delivered over a physical or logical link, or pass through a certain network node [3][4].

The throughput is usually measured in data packets per second or data packets per slot and sometimes bits per second (bit/s or bps). The system throughput or aggregate throughput is the sum of the data rates that are delivered to all the terminals in a network. Packet delay is one of the most important parameter to analyze the performance of wireless network.

2. EXPERIMENTAL SETUP

A. Analytical Model
A station can initiate a transmission when the back-off timer reaches zero [8]. The back-off time is uniformly chosen in the range (0, w-1). Also (w-1) is known as Contention Window (CW), which is an integer with the range CWmin and CWmax determined by the PHY characteristics. After every abortive data transmission, the time ‘w’ is doubled, up to a maximum value 2mW, where W equals to (CWmin+1) and 2mW equals to (CWmax+1).

B. (i) Throughput Analysis
In order to determine the throughput of a system it is necessary to analyze the MAC layer [7] of the system. A data packet consists of overhead (preamble and header) and the data portion. The time to transmit this packet $t_T$ is shown below

$$t_T = DIFS + OVERHEAD + \frac{DataBits}{Rate\times Bit\times Sec} + SIFS + ACK$$

(ii) Binary Exponential Backoff (BEB) algorithm
In the IEEE 802.11 standard MAC protocol, the Binary Exponential Back-off (BEB) algorithm is used. In BEB, when a node over the network has a packet to send, it first senses the channel using a carrier sensing technique. If the channel is found to be idle and not being used by any other node, the node is granted access to start transmitting. Otherwise, the node waits for an inter-frame interval time and the back-off mechanism is invoked, and the random back-off time will be selected in the range [0, CW-1]. A uniform random distribution is used here, where CW is the current contention window size. The following equation is used to calculate the back-off time (BO)

Back-off time (BO) = (Rand () MOD CW) * a Slot Time

If the medium is found to be idle then the back-off period is decremented by one time slot.

Back-off time (BO) new = (BO) old – a Slot Time

If the medium is determined to be busy during back-off, then the back-off timer is suspended. When back-off is finished with the back-off time (BO) value of zero, a data transfer should take place. If the node succeeded to send a packet and receive an acknowledgment for it, then the CW for this node is reset to the minimum, which is equal to 31 in the case of BEB. If the transfer fails, the network node goes into another back-off period. When going for another back-off period again, the contention window size is exponentially increased with a maximum of 1023. The BEB algorithm uses the following equation to increase the contention window size

Back-off time (BO) = (Rand () MOD CW) * a Slot Time
C (i) Fragmentation in IEEE 802.11
Fragmentation is the process of dividing a long frame into short frames. Fig.1 illustrates the fragmentation process in IEEE 802.11 MAC.

(ii) Throughput Analysis
The performance of the wireless Communication network can be evaluated in terms of QOS parameters like throughput, packet delay and packet delivery ratio, packet drop etc. Let n be the fixed number of contending stations and $\tau$ be the probability that a station transmits the packets in a randomly chosen slot time. Since a station transmits when its back-off timer reaches the value of zero, the equation for $\tau$ using BEB can be written as [9]

$$\tau = \frac{2w(1-2p)(1-p)}{1-(2p)^{n+1}+(1-2p)(1-p)^{n+1}}$$  \hspace{1cm} (5)

Where P is the probability of collision W is the contention window size and m is the retry limit.

The probability that at least one station transmits during slot time i.e. probability that the channel is busy is given as

$$P_b = 1-(1-\tau)^n$$  \hspace{1cm} (6)

Now the probability of collision $P_c$ or the probability of any one of the $n-1$ nodes transmitting a packet $P_{tr}$ in an idle time can be expressed as

$$P_c = P_{tr} = 1-(1-\tau)^{n-1}$$  \hspace{1cm} (7)

The probability of successful transmission, $P_s$ can be expressed as:

$$P_s = \frac{nP_s(1-\tau)^{n-1}}{1-(1-\tau)^n}$$  \hspace{1cm} (8)
The throughput considering the transmission errors can be derived as

$$S = \frac{P_s(1 - P_{\text{frg error}})L}{P_s(1 - P_{\text{frg error}})T_{\text{success}} + (1 - P_s)T_{\text{collision}} + T_{\text{idle}} + P_sP_{\text{frg error}}T_e}$$ \hspace{1cm} (9)$$

Where \(L\) is the average packet payload size, \(T_{\text{success}}\) is the average time that the channel is captured for a successful transmission with fragmentation, \(T_{\text{collision}}\) is the average time that the channel is captured by stations which collide, \(P_s\) is the probability that a transmission is successful and \(T_e\) is the unsuccessful packet transmission time due to transmission errors. Here, \(T_{\text{collision}}\) and \(T_e\) are assumed to be same. \(L, T_{\text{success}}, T_{\text{collision}}\) and slot time must be expressed in same units.

D. Packet Delay Analysis

The delay performance of IEEE 802.11 protocol can be done by taking the retry limits of a data packet transmission into account. The packet drop probability is defined, as the probability that a packet is dropped when the retry limit is reached and it is equal to

$$p_{\text{drop}} = P^{m+1}$$ \hspace{1cm} (10)$$

The average length of a slot time is

$$E[\text{slot}] = (1 - p_{\text{tr}})\sigma + p_{\text{tr}} \cdot p_s T_s + p_{\text{tr}} (1 - P_s) T_e$$ \hspace{1cm} (11)$$

Finally, the average time to drop a packet is equal to

$$E[D_{\text{drop}}] = E[T_{\text{drop}}] E[\text{slot}]$$ \hspace{1cm} (12)$$

The average packet delay \(E[D]\), provided that this packet is not discarded, is given by

$$E[D] = E[X] E[\text{slot}]$$ \hspace{1cm} (13)$$

Where \(E[X]\) is the average number of slot times required for successfully transmitting a packet and is given by

$$E[X] = \frac{(1 - 2p)(cw + 1) + p_cw(1 - (2p)^+)}{2(1 - 2p)(1 - p)}$$ \hspace{1cm} (14)$$

E. Load Analysis

The load probability is not constrained to a specific traffic model, and generally a Poisson traffic model is adopted in both modeling and simulations. The load modeling and simulation Analysis have adopted the Poisson traffic model. In [10-13] it is assumed that traffic arrive with at rate \(\lambda\) in Poisson manner. The basic estimation of load probability \(q\) is expressed as

$$q = 1 - e^{\lambda T}$$ \hspace{1cm} (15)$$

The probability, \(q\), that there is at least one packet available in buffer for transmission can be expressed as

$$q = (1 - e^{\lambda T})(1 + q_{\text{tmp}})/(1 + (1 - e^{\lambda T})q_{\text{tmp}})$$ \hspace{1cm} (16)$$
Saturation and Non-Saturation Throughput and Packet Delay Analysis of IEEE 802.11 DCF For AD-HOC Networks

Where $q_{\text{temp}} = (P + (1 - P)P)/(1 - P)^2$

F. Transmission Probability
The transmission probability equation in [12] is given as:

$$\tau = \frac{q^2 w_o}{(1 - q) - (1 - q)^w_o} = \frac{q^2 (1 - P)}{1 - q}$$  (17)

3. RESULTS AND DISCUSSIONS
The simulation parameters used for analyzing the throughput of IEEE 802.11b network are shown in table.

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slot time</td>
<td>20 µs</td>
</tr>
<tr>
<td>SIFS</td>
<td>10 µs</td>
</tr>
<tr>
<td>DIFS</td>
<td>50 µs</td>
</tr>
<tr>
<td>Minimum Contention Window</td>
<td>31</td>
</tr>
<tr>
<td>Maximum Contention Window</td>
<td>1023</td>
</tr>
<tr>
<td>Channel bit rate</td>
<td>1, 2, 5.5, 11 Mbps</td>
</tr>
<tr>
<td>PHY header</td>
<td>24 Bytes</td>
</tr>
<tr>
<td>MAC header</td>
<td>28 Bytes</td>
</tr>
<tr>
<td>RTS</td>
<td>44 Bytes</td>
</tr>
<tr>
<td>ACK</td>
<td>38 Bytes</td>
</tr>
<tr>
<td>Propagation delay, $\delta$</td>
<td>2 µs</td>
</tr>
</tbody>
</table>

![Figure 2 SNR versus Throughput](image)

The throughput analysis of IEEE 802.11b with various fragment lengths using DBPSK is shown in the Fig.2. The throughput increases with increase in the fragment length.
Fig. 3 plots the Fragment size versus throughput at various bit error rates. Here, the bits are transmitted at 1 Mbps and the number of contending nodes is set at 25. The constant contention window is used and is set at 100. The overhead for the smaller fragments is relatively large compared to larger fragments. But if the larger fragments are corrupted due to noisy channels, the entire fragment is to be retransmitted. It is observed that as the fragment size increases, the throughput decreases and the optimal fragment size depends on the BER. If the BER is known, the optimal fragment size can be selected. In this case, the optimal fragment size is 256 bytes for BER $10^{-4}$ and 512 bytes for BER $10^{-5}$ and $10^{-6}$ respectively.

Fig. 4 Number of nodes versus throughput (fragment size = 256 bytes, BER = $10^{-6}$)
Figure 5 Number of nodes versus throughput (fragment size = 512 bytes, BER = $10^{-6}$)

Here, the number of stations is varied and uses the packet size of 2000 bytes and fragment size of 256 bytes is taken in Fig.4 and 512 bytes in Fig.5. The probability of collision increases with increase in number of contending nodes and hence the throughput decreases. But the throughput can be increased by selecting the proper contention window even the number of nodes increases. Here, the optimal contention window size is 300. If the contention window is set at 500, the throughput is better but it does not work if the numbers of nodes are less than 20.

Figure 6 Number of nodes versus Delay

The packet delay analysis for various nodes using BEB and Constant contention window algorithms is plotted in Fig 6. The packet delay reduces by properly selecting contention window size in constant backoff algorithm. If the contention window is selected as 300, one can get the minimum packet delay which is very important.

4. CONCLUSION

Simulation results shows that the packet delay increases and throughput decreases in BEB compared to Constant backoff algorithm. The optimal fragment size and optimal contention window are determined to achieve the maximum throughput for the specified BER.
REFERENCES


