Throughput Model of IEEE 802.11 DCF Considering Multi-Rate

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Abstract

Accurately modeling the IEEE 802.11 DCF is critical to analyze the performance of wireless LAN. However, current models cannot express network performance correctly in the case of multi-rate due to its normalized throughput definition. Therefore, a new Markov model with absorbing state is proposed based on the comprehensive analyses and researches, and the system throughput is redefined. Simulation results show that the proposed model can exhibit the throughput performance of network system, and provides more precise modeling when considering multi-rate situations.

Keywords: wireless LAN; IEEE 802.11 MAC; DCF; multi-rate; throughput evaluation

1. Introduction

With the rapid developments of cost declining and transmission speed enhancing, the technology of WLAN has been used widely. Plenty of good ideas have been contrived to analyze the performance of IEEE 802.11 DCF mechanism and recommend correction approaches. A Markov chain model [2] has been presented by Bianchi using binary exponential backoff algorithm, which establishes the theoretical expression of IEEE 802.11 DCF throughputs in saturation conditions successfully. The articles [34] are published to take the limitation of retransmission numbers and the freeze of window timer into account, making the throughput model of backoff mechanism more and more legitimate.

The IEEE 802.11 protocol stack standards are updated constantly to enhance the physical communication speed by modifying the physical layer technology. Moreover, it also increases network throughput [1, 5-6]. Bianchi's saturation throughput model accurately reveals the trend of network throughput in network saturation conditions. As the number of stations changes, the size of contention window and the number of retransmission show variety accordingly. However, the system normalized throughput of this model is defined as the ratio of load transmission time in time slot to the length of time.
slot. It is a probability percentage which is inversely proportional to the data transfer rate, and it cannot correctly reflect the influence of the data transmission speed to the throughput.

Based on the 2-dimension Markov chain model proposed by Bianchi, this paper proposes a new throughput model of IEEE 802.11 DCF, which considers the influence of transmission rate to the network performance, and analyses the performance under different IEEE802.11 sub-standard using our throughput parameters. The simulation results verify the effectiveness of this theoretical analysis model.

The paper is organized as follows. In Section II, we improve the model of DCF Markov chain. In Section III, the new throughput model based on the DCF analysis procedure is presented. Section IV describes simulation and analysis of results. Finally, the paper is concluded in Section V.

2. The Model of DCF Markov Chain

Assume that the system contains 1 AP and n stations. The communications between the stations and AP are unobstructed. Each station has data to send.

The stationary random probability of transmission frames of a station at any time is $\tau$, and the probability of system which has a frame to transmit at any time is

$$P_\tau = 1 - (1 - \tau)^n.$$  \hspace{1cm} (1)

Meanwhile, assume that there is no collision in the system, and then the probability of successful transmission can be written as

$$P_s = C^n_1 \tau (1 - \tau)^{n-1} = \frac{n \tau (1 - \tau)^{n-1}}{1 - (1 - \tau)^n}.$$  \hspace{1cm} (2)

Under the ideal communication channel, The retransmissions of MSDU or MMPDU’s frames are all caused by collision, so the probability of retransmission is:

$$p = 1 - (1 - \tau)^n.$$  \hspace{1cm} (3)

Use $b_{i,j}$ to represent the steady-state distribution of Markov chain, in which $i$ and $j$ denote the retransmission and the random backoff time, respectively.

$$b_{i,j} = \lim_{t \to \infty} P\{s(t) = i, v(t) = j\}, i \in [0, m], j \in [0, W_i - 1]$$  \hspace{1cm} (4)

In this paper we introduce the absorbing states bs and bf into the Markov chain model to stand for a successful sending and a fail sending, respectively. The Markov chain model is shown as Fig. 1, where $W_i$ is the length of maximum window for the ith retransmission, and $m$ is the maximum number of retransmission. For each additional retransmission, doubling the length of maximum window occurs, whereas this case is limited by $m'$. According to the CWmax in IEEE 802.11x standards [1, 5-6], the $m' = 5$ in IEEE 802.11b, $m' = 6$ in IEEE 802.11g and IEEE 802.11a.
The added absorbing state in this model does not involve the analysis of backoff mechanism, so it does not affect the parameter $\tau$.

From analysis of Markov model, the $\tau$ can be expressed as

$$\tau = \sum_{i=0}^{\infty} b_{i,0} = \frac{1 - p^{m+1}}{1 - p} b_{0,0}. \quad (5)$$

According to the deduction approach in [3], we can get:

$$\tau = \begin{cases} 
\frac{2(1-2p)(1-p^{m+1})}{W(1-2p)(1-p^{m+1})} & m \leq m' \\
\frac{2(1-2p)(1-p^{m+1})}{W(1-2p)(1-p^{m+1}) + W2^{m'} p^{m+1} (1-2p)(1-p^{m+1})} & m > m' 
\end{cases} \quad (6)$$

(3) and (6) constitute a non-linear equations set, from which the parameters $\tau$ and $p$ can be solved by numerical method, and then the $b_{i,j}$ can be obtained.

For convenience, this paper assumes $m < m'$. The following analysis is only for $m < m'$.

3. Analysis of DCF throughput mechanisms

The transmission error may be caused by many factors. The error recovery approach of IEEE 802.11 MAC mechanism is usually executed by the station with data frame to send in the retransmission method.

The collisions of data frames easily result from more stations sharing the same system channel, the presence of hidden/exposed terminals or other reasons. According to Markov model, the mathematic expectation of data frame collisions’ number is

$$N_C = \sum_{i=0}^{m} \sum_{j=0}^{W-1} (b_{i,j} \times i) \quad (7)$$

The probability of the state is $b_{i,j}$, if the station is in the $i$th retransmissions stage and the $j$th back-off stage, in which the backoff length is $j$. So the average length of the backoff window can be expressed as

$$W = \sum_{i=0}^{m} \sum_{j=0}^{W-1} (b_{i,j} \times j) \quad (8)$$

$N_C$ reflects the status of the channel occupied in the data frame backoff process. It can be expressed as...
In the case of collisions, STA set a backoff time, which length is random integer multiple of a slot. The backoff timer keeps frozen when the channel is busy. So the average backoff time of the data frame can be written as

$$\bar{T}_b = \bar{W} \times \sigma + \overline{N}_F \times (P_s T_s + p T_c),$$

where $\sigma$ is the length of a time slot. $T_s$ is the number of time slot in a successful transmission. $T_c$ is the number of time slot in a collision. Their RTS/CTS can be express as

$$T_s = DIFS + T_{RTS} + T_{CTS} + T_{Idle} + T_{busy} + SIFS + T_{ACK} + 2\delta$$

$$T_c = DIFS + T_{RTS} + SIFS + \delta + T_{CTS}$$

$\delta$ is propagation delay, TX above is transmission time for X type data frame.

$$T_X = \frac{L_X}{R}$$

$L_X$ is frame length for X type and $R$ is data transmission time.

So the actual system throughput is defined as

$$S = \frac{L_{Data}}{P_s [(T_s + T_c) + N_c (T_s + T_c)] + (1 - P_s)[m(T_s + T_c)]}$$

4. Simulation and analysis

In order to verify the accuracy of this model, this paper makes some simulations to observe and investigate the system throughput performance. We set the simulation parameters in accordance with provisions in [1].

Fig.2 shows the influence of the number of STAs within network to system throughput in ideal channel. The “+” describes the simulation results obtained by NS-2, and “o” stands for the theoretical values come from Markov model. We set the number of STAs as 5, 6, 7, 8, 10 and 15 in NS-2. The positions of the stations in simulation are confirmed randomly. Each type of number setting is simulated 3 times to remove the effect on system throughput caused by the random of the STAs’ position.

The results demonstrate that the system throughput fluctuates in a certain extent according to the change of STAs positions. With the number of stations participated in channel contention increasing, the network...
collision will also increase. The rate of successful transmission decreases at the same time. The throughput from mathematic calculation based on Markov model decrease with increasing of stations, which agrees with simulation in NS-2.

The system normalized throughput is defined as the ratio of load transmission time to the length of time slot in [2]. In this defined throughput, the load transfer time decrease with the transmission rate increasing, and then the normalized throughput declines subsequently. Simulation results in Fig. 3 show the changing tendency.

![Figure 3. Throughput of the original model](image)

Actually, the throughput indicators defined as data frame received within unit time are more significant than a normalized throughput in network simulation and engineering tests. In this definition, the system throughput becomes higher with transmission rate increasing. IEEE 802.11g OFDM modulation supports 6 types of rates, which are 6, 9, 12, 18, 24, 36, 48, 54Mbps. The simulation results in Fig. 4 show that, as the transmission rate increases, the system throughput also increases.

![Figure 4. The system throughput with data transfer rates changes in improved model](image)

5. Conclusion

In this work we revise the original Markov model by identifying the absorption states of successful receiving and fail sending. In view of the original DCF mechanism analysis model cannot properly reflect the system performance under the multi-rate situation, this paper presents a new throughput model of IEEE 802.11 DCF mechanism considering the multi-rate situations. The simulation results show that the throughput of system increases as long as the data rate increase under the multi-rate of the IEEE 802.11x
standards. The new analytical model can describe the changing tendency exactly in the case of multi-rate of the IEEE 802.11 standard.

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References

[1] IEEE 802.11, Part 11: Wireless LAN medium access control (MAC) and physical layer (PHY) specifications. 1999