Abstract. IEEE 802.11 is the most popular standard used in WLAN. Distributed Coordination Function (DCF) is one of the channel-access methods in the IEEE 802.11 Medium Access Control (MAC) protocol. However, it has not been adequately studied under the existence of hidden stations. In the paper, we present the novel saturated throughput analysis of the IEEE 802.11 DCF in the presence of hidden stations. This approach involves a novel analytical model that is an extension to previous works by other authors which provide Markov chain analysis to IEEE 802.11 DCF. The throughput analysis of our model is evaluated by comparison with NS2 simulations and found the model is accurate and suitable for both basic access and request-to-send/clear-to-send (RTS/CTS) access mechanisms.

Keywords: throughput, IEEE 802.11 DCF, saturation, hidden stations.

1 Introduction

The IEEE 802.11 wireless local area networks (WLAN) have experienced great achievement due to their low cost and simple deployment [1]. Hidden stations cause most collisions because stations cannot sense each other’s transmission and often send packets concurrently, resulting in significant degradation of the network performance. The performance impact on the IEEE 802.11 DCF is a significant concern in the conditions of hidden stations, and it deserves to be researched under diverse assumptions [2].

Bianchi [3] is the first to originate a model for the saturation throughput of IEEE DCF that merge the exponential backoff mechanism with 2-D Markov chain. Kim and Lim [4] identified the coupling effect when the number of stations is small (less than 8), in which case this conditional collision probability highly depends on the backoff process of other stations. Tsertou and Laurenson [5] identify an important phenomenon of the lack of time-synchronization between the hidden stations. Kim and Choi [6] study a simple ad hoc network with two transmission pairs. According to [7, 8], the transmission probabilities of a hidden station during two successive slots
are not independent. Ref. [9, 10] model the probability that a hidden station will not transmit during the vulnerable period of the successive slots as another parameter. Therefore, The channel access contention of a station with other terminal stations changes the accuracy of modeling [11].

To tackle the challenges, We propose a novel discrete time 3-D Markov system. The fixed small slot represents the situation that each station may observe different actions on its backoff counter. Then combine with a spatial-temporal analysis. It can generalizes the existing work on the performance modeling of the 802.11 DCF and it is not complex but accurate approximate solution model which reflects the hidden station effect clearly [9, 12].

The rest of this paper is arranged as follows. In Section 2, we propose a Markov chain based model with equivalent state transition to analyze the average throughput performance of DCF with hidden terminals under saturated conditions. The accuracy of our model is validated by comparing analytical result with that by NS2 in Section 3. Finally, the conclusion is given in Section 4.

2 Analytical Model

In the analysis performance, the Markov chain model is based on the model in [11] with equivalent state transition: (1) \( s(t) \) is defined as the number of backoff stages; (2) \( b(t) \) is the backoff counter; (3) \( v(t) \) is the residual time slot during either freezing, transmission or collision. We use \( P\{i_1, j_1, k_1|i_0, j_0, k_0\} \) to denote the probability \( P\{s(t+1)=i_1, b(t+1)=j_1, v(t+1)=k_1|i_0, j_0, k_0\} \) for state transition. Since the chain is regular, so for each state, we have

\[
1 = \sum_{i=0}^{\infty} \sum_{j=0}^{i} \sum_{k=0}^{j} b_{i,j,k} + \sum_{i=0}^{\infty} \sum_{j=0}^{i} \sum_{k=0}^{j} b_{i,j,k} + \sum_{i=0}^{\infty} \sum_{j=0}^{i} \sum_{k=0}^{j} b_{i,j,k}
\]

\[
= \sum_{i=0}^{\infty} b_{0,0,0} \cdot (W-1)[(1-p_a)p_s^{-1} + 1]/2 + 1 + p(L_c-1)
\]

\[
+ b_{0,0,0}(1-p^{m+1})(L_c-1)
\]

And then, we have,

\[
b_{0,0,0} = [(1-p^{m+1})(L_c-1) + \frac{W(1-2p)^{m+1}}{2} \frac{1+p_b-p_s}{p_b} \\
+ \frac{1-p^{m+1}}{1-p} \frac{1+p_s-p_c}{2p_s}][1]
\]

Now the probability \( \tau_1 \) can be expressed as:

\[
\tau_1 = \sum_{n=0}^{\infty} b_{n,0,0} = \frac{1-p^{m+1}}{1-p} b_{0,0,0}
\]
2.1 Collision Probabilities And Throughput Analysis

As in [11], the probability \( p \) that a transmitted packet collides with others is independent of the state \( s(t) \) of the station can be expressed as:

\[
p = 1 - (1 - \tau_1)^{s-1}(1 - \tau_2)^{s}
\]  

(4)

One of the parameters \( \tau_2 \) denotes the stationary probability that a hidden station will transmit during the vulnerable period and collide with the frame transmitted by the source. Let \( P_{\nu} \) be the probability that there is at least one transmission in the considered slot time. Therefore, \( P_{\nu} \) can be expressed as:

\[
P_{\nu} = 1 - (1 - \tau_1)^{s}
\]  

(5)

The probability of a successful transmission \( P_s \) can be expressed as:

\[
P_s = \frac{\nu \tau_1 (1 - \tau_1)^{s-1}(1 - \tau_2)^{s}}{P_{\nu}}
\]  

(6)

Then, the normalized system throughput \( S \) can be expressed as:

\[
S = \frac{P_s P_e E[P]}{(1 - P_s)\sigma + P_s P_e T_e + (1 - P_s)P_e T_e}
\]  

(7)

The derivation of the formulae of \( p_a \) and \( p_b \) have been elaborated in [9] and the formula of \( \tau_2 \) is given in [11]. By analysing the derivation in [9], the equation (2) can approximatively equivalent to the equation (8).

\[
b_{0.0.0} = \left[ \frac{16(1 - 64p^\nu)}{1 - 2p} + \frac{1 - p^\nu}{2(1 - p)} \right]^{-1}
\]  

(8)

We can solve the nonlinear relevant equations to obtain \( \tau_1 \) and \( \tau_2 \) by a numerical method. Then we can obtain the value of the normalized system throughput [11].

3 Model Evaluation

All the parameters used in the analytical model and the NS2 simulation are summarized in Table 1. This topology that we use is composed of one access point located in the center of a ring and some stations uniformly distributed on the ring. We set the initial value of these parameters and further analysis as follows: (i) the number of stations in the ring topology is 5, 10, 15, 20, 25, 30, 35 and 40 respectively; (ii) we consider the some various number of the hidden stations such as 0, 1, 3, 5 on the designed different number of stations; (iii) the transmission range and carrier sensing ranges are set at 250 meters. In this study, we vary \( d \) to obtain different number (0, 1, 3, 5) of hidden stations in the network [13].
We compare the numerical results with simulations ($x$ is the number of hidden stations). The simulation results in Fig.1 and Fig.2 show the accuracy of our model in both the basic and RTS/CTS cases.
4 Conclusion

In this paper, we derived an analytical model to compute the saturated throughput of the IEEE 802.11 DCF in the presence of hidden stations for both the basic and RTS/CTS access methods. The proposed model is in good agreement with NS2 simulations in most condition and, thus, can be used to estimate the network throughput. The existing models can be considered as special cases of our model with zero hidden stations.

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References