International Journal For Technological Research In Engineering
Volume 3, Issue 8, April-2016 *ISSN (Online): 2347 - 4718*

TWO STOCHASTIC APPROACHES FOR THE ANALYSIS OF DISTRIBUTED CO-ORDINATION FUNCTION OF WLAN

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Abstract: Wireless communication networks are continuously evolving, both in terms of data rates and variety of services, as they have advantages of mobility support and flexibility. Wireless Local Area Network (WLAN) is one such network. It employs Distributed Co-ordination Function (DCF) with Carrier Sense Multiple Access /Collision Avoidance (CSMA/CA) protocol, which is the mandatory access method. However, complexities in WLANS such as distributed operation, dynamic topology, channel fading due to time varying wireless link, multi-user interference and limited power at the nodes make their design a challenging task. In this paper, two stochastic approaches are summarized to analyze the DCF of WLAN. First one is Discrete Time Markov Chain Model model and second one is based on renewal reward theorem. It has been reported that both approaches are equally accurate in analyzing DCF.

I. INTRODUCTION

Last few years have witnessed a phenomenal growth in the wireless and networking systems, both in terms of their variants and wide spread applications. For example communication systems have migrated from first-generation systems, which are primarily focused on voice communication, to third generation systems dealing with internet connectivity and multimedia applications [1, 2]. The fourth generation cellular systems are proposed to be designed to connect wireless personal area network (WPAN), wireless local area network (WLANs) and wireless wide-area networks (WWAN). Similarly there are multiple variants of IEEE 802.11(Wi-Fi) and 802.16 networks (Wi-Max) [3].The design, development, modeling, analysis and performance evaluation of a wireless network is more challenging and complex than that of wired network. Therefore, extensive research has been done over the past decade which has led to the evolution of various techniques, for improving WLAN system performance under different practical conditions. WLAN uses random access based MAC protocols, in which nodes access the medium randomly without the reservation of time slot or frequency band for any station [4]. There are two types of random access protocols: non-carrier sensing and with carrier sensing. WLAN uses CSMA/CA in association with DCF mechanism. It is a fundamental mechanism for channel access in distributed environment. This paper describes two approaches for the analysis of DCF. The first one is based on DTMC Model of Bianchi and second approach uses renewal reward theorem.

II. RELATED LITERATURE

A. CSMA/CA Mechanism

CSMA/CA is a specialized MAC protocol for a wireless environment [5], which can be described in following steps:

(1) The backlogged station first senses the channel. If the medium is idle for the specified duration, called as inter-frame space (IFS) delay, the node starts its transmission on the channel once. If more than one station tries to access the channel for transmission, additional mechanism is required.

(2) If the channel is initially busy, or becomes busy within IFS time duration, the node waits till the medium becomes free. As soon as the medium becomes free, the node waits for additional IFS duration and enters into a contention phase for transmission.

(3) In contention phase, each node chooses a random back-off time within a contention window and delays its medium access for this random amount of time.

(4) Each node continues to sense the medium; as soon as a node senses that the channel is busy (due to occupancy of the medium by another station with lesser waiting time), it has lost this cycle and has to wait for the next chance for remaining waiting period, until the medium is idle again for time duration of at least IFS.

(5) If the randomized additional waiting time for a node is completed and the medium is still idle, the node can access the medium immediately. The additional waiting time is measured in multiples of the above mentioned time slots. This additional randomly distributed delay helps to avoid collisions.

(6) Unfortunately if two nodes have to wait for the same amount of time, collision is unavoidable. After collision, the contention window follows the binary exponential back-off (BEB) mechanism, in which the size of window is doubled after each collision.

(7) Station then chooses a random number from expanded contention window for its contention and executes step 4 and 5, in case of successful transmission. However, in case of collision steps 4 to 7 are repeated up to some maximum limit. After this limited either the packet is treated as a new one or it is dropped.

B. Inter-frame space delay

Shortest inter-frame space delay (SIFS) is the shortest waiting time for medium access and is provisioned for frame transmission of highest priority. It is used for the transmission of acknowledgement frames or polling responses from secondary stations. Point Co-ordination Function (PCF) inter-frame space delay, PIFS is the moderate waiting time, which is more than SIFS, and is used for a time-bound service such as contention free cycle of PCF. DCF inter-frame space delay is the longest waiting time and has the lowest priority for medium access. This delay is used for frame transmission with asynchronous data service within a contention period [5].

C. Distributed Co-ordination Function (DCF)
This is a basic access method in 802.11 and is based on CSMA/CA with a random back-off as shown in figure 1. A DCF station has to wait for DCF inter-frame space delay (DIFS) period as inter-frame space delay. Two or more stations which are waiting for transmission enter into a contention phase and choose a random delay. If these stations transmit at the same time, collision takes place. After collision, the contention window follows the binary BEB [6] algorithm to reduce the future possibility of collisions. This basic mechnism can be provisioned with an RTS/CTS extention to avoid the hidden terminal problem.

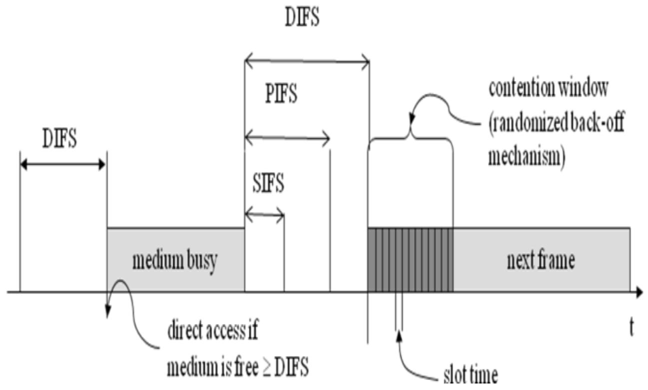

Figure 1 DCF Mechanism

III. PERFORMANCE EVALUATION OF DCF

Performance evaluation of DCF allows system designers to obtain quantitative insights into the effectiveness of the DCF mechanism. In the subsequent section a model has been described for accurate performance evaluation of the DCF employed in the IEEE 802.11 [7].

A. DTMC Model

Bianchi developed the DTMC (Discrete Time Markov Chain) model to characterize DCF and derive analytical expressions for bound on the maximum achievable throughput by DCF. A two-dimensional Markov chain was proposed. The following assumptions are made to model DCF [8].

(1)Each station is in saturation condition.

(2) The station's buffer is always non-empty and a frame is always available for transmission [8, 9].Frame transmission is never corrupted.

(3)A frame transmission is never corrupted by noise, channel fading or by interference due to hidden terminals.

(4)Frame transmission fails only when there is a collision with another frame on the channel.

A backlogged station is initially in stage one. It randomly selects a slot number for packet transmission from its contention window, of sizeW0, which is the size of the contention window of the first stage. A number is selected randomly from the range [0-W0]. At the beginning of each time slot, the station decrements its counter value by one and when the counter value becomes zero it attempts to transmit the packet. In general, at a given slot time, one of three possible events may occur: successful transmission by some station, collision due to simultaneous transmission by two or more packets, or a slot remains idle due to non-transmission by any station. In case of packet collision, station moves to a higher stage, doubles the size of the contention window and randomly selects a new back-off counter value. In binary exponential back-off algorithm, the contention window size after i unsuccessful packet transmission attempts, Wi, is given by $W_i = 2^i W_0$ where i is the back-off stage and W0 is the initial size of contention window. The same procedure is repeated to determine the slot number for its transmission attempt in higher stages. However, in case of successful transmission the station moves to stage one, irrespective of its state at the time of transmission.

Let there be n number of stations in a BSS. Regardless of the number of re-transmissions attempted let the probability that a packet transmitted by each station encounters collision, is denoted by p. Collision probability is assumed to be constant and independent of number of retransmission of a packet. In other words, p can be considered as the conditional probability of a packet encountering a collision while being transmitted on the channel in any back-off stage [8], and is given by:

$$p = 1-(1-\tau)^{n-1} \quad (1)$$

Let B(t), one dimension of the DTMC, be the stochastic process representing the back-off time counter for a given station. A discrete and integer time scale is adopted where t and t+1 correspond to the beginning of two consecutive slot times. The back-off time counter of each station decrements at the beginning of each slot time. In fact, the back-off counter time decrement is halted when the channel is sensed busy, and thus the actual time interval between two consecutive time slot beginnings, t andt+1 may be much longer than the slot time size. Since the value of the back-off counter of a station depends on its transmission history, the stochastic process of B(t) is non-Markovian [8].

Let S(t), another dimension of DTMC, be the stochastic process representing the back-off stages, where i varies between 0 and K of the station at time t in which K is the highest back-off stage. Based on the assumption that p, collision probability, is constant and independent, the bi-directional process (S(t), B(t)) can be modeled by a discrete-time Markov chain as shown in figure 2 [8, 9].

This complete process is modeled by the following non-zero one-step transition probabilities given by 2.36 (i) to (iv)

$$\begin{array}{lll} \Pr\{i,k \mid i,k+1\} = 1 & \text{for } k \in (0, W_i - 1), i \in (0,K) & \text{(i)} \\ \Pr\{0,k \mid i,0\} = (1-p)/W_0 & \text{for } k \in (0, W_0 - 1), i \in (0,K) & \text{(ii)} \\ \Pr\{i,k \mid (i-1),0\} = p/W_i & \text{for } k \in (0, W_i - 1), i \in (0,K) & \text{(iii)} \\ \Pr\{K,k \mid K,0\} = p/W_K & \text{for } k \in (0, W_K - 1) & \text{(iv)} \end{array} \quad (2)$$

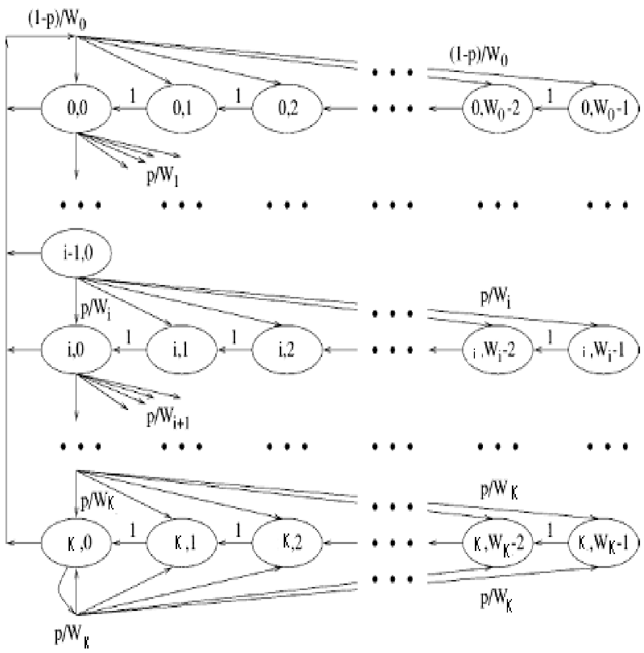

Figure 2 Two dimensional DTMC Model

Using model equations (1) & (2), the probability of transmission τ can be given by [8]

$$\tau = \frac{2}{1 + W_0 + pW_0 \sum_{i=0}^{K-1} (2p)^i} \quad (3)$$

τ is also called as attempt rate, which is the ratio of the average number of transmission attempts made by a node between successful transmissions to the average random amount of cumulative back-off time between successive successful packet transmissions. Equations (1) and (2) represent a nonlinear system of equations with two unknowns, τ and p, which can be solved using numerical techniques.

B. Model Based on Renewal Reward Theorem

The DCF of an IEEE 802.11 WLAN has been modeled as a two-dimensional Markov chain by Bianchi in [8]. In [9], a simplified and generalized analysis of the DCF is performed. Modeling and analysis of the DCF for the proposed schemes is based on a generalized frame work and with similar assumptions as described in [9]. These assumptions are as follows [10]:

(i)The transmission queue of each station is always non-empty.

(ii) All stations are homogeneous i.e., the back-off parameters of all the stations are the same.

(iii) At each transmission attempt, each packet collides with a constant and independent collision probability p, which is independent of other packet transmissions.

(iv) A packet is discarded after the (K+1)th successive collisions.

(v) The nodes are assumed to attempt a transmission in each slot with a constant transmission probability, which is equal to the average attempt rate τ.

Let t_{bo} be the random amount of cumulative back-off time between successive successful packet transmissions or packet discard at a node, N_{ta} be the number of transmission attempts made by a node between successful transmissions or packet discard, including the attempt that resulted in a successful transmission or discard. With renewal assumptions, and viewing the attempts as a reward in a renewal cycle, the average attempt rate of a node, which is also the probability of transmission of a packet in a random chosen time slot, using renewal reward theorem [10, 9] is given by

$$\tau = \frac{E(N_{ta})}{E(t_{bo})} \quad (3)$$

Let b_i be the mean back-off duration after the ith collision and p be the probability of collision. Then average random amount of cumulative back-off time between successive successful packet transmissions E (t_{bo}) is given by

$$E(t_{bo}) = b_0 + p(b_1 + p(b_2 + p(\ldots\ldots(\ldots + (pb_i))))) \quad (4)$$

The minimum value of t_{bo} is b_o, which is back-off value after first attempt. In case of packet collision with probability p, variable random back-off time, t_{bo}, is augmented by pb1, which is further increased by successive collisions. Therefore, the average number of attempts made by a node, E(Nta), is given by

$$E(N_{ta}) = 1 + p + p^2 + \ldots\ldots + p^i \quad (5)$$

Using (4.1), (4.2) and (4.3), the long run average attempt rate or transmission probability, τ for each node is given by

$$\tau = \frac{\sum_{i=0}^{K} p^i}{\sum_{i=0}^{K} b_i p^i} \quad (6)$$

The mean back-off duration after i collisions bi, depends on the range of the contention window at the ith stage and the probability distribution of the CS in different stages of the station. Equations (1) and (6) form a system with non-linear equations which can be solved numerically.

C. Discussion

It has been reported in the literature that mathematical analysis of DCF using both of these approaches computes the same value of attempt rate, collision probability, network throughput and delay. Therefore any of these approaches may be used for the analysis of DCF and computation of network parameters.

IV. CONCLUSION

Design and analysis of such WLANs is a challenging task due to the inherent complexities in such systems such as distributed operation, dynamic topology, time varying wireless link (fading channel), propagation path loss, multi-user interference and limited power at the nodes. Therefore, extensive research has been done over the past decade which has led to the evolution of various techniques, for improving and analyzing the WLAN system performance under different practical conditions.

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