Delay Analysis of IEEE 802.11 DCF with modified Binary Exponential Backoff

Rishipal Singh[1,2], D.K.Lobiyal[2]

[1]Department of CSE, Guru Jambheshwar University of Science and Technology, Hisar, India

[2]School of Computer and Systems Sciences, Jawaharlal Nehru University, Delhi, India

Abstract

In the design of wireless networks the medium access control (MAC) protocols have a very high impact on the performance of the network. The IEEE 802.11 is widely accepted technology for the Wireless LANs has been used by wireless networks. Delay is one of the important parameter to measure the performance of the wireless networks. We give a delay analysis of the Distributed Coordination Function of IEEE 802.11 under modified Binary Exponential Backoff (BEB) Algorithm using Frequency Hoping Spread Spectrum (FHSS). In the modified BEB, initially the contention window size increases with the factor of √2 for first four collisions and after that for more collisions the size of contention window gets double. The size of contention window varies between CW_{min} and CW_{max}. Markov chain has been used for the analysis of IEEE 802.11 DCF for both modes basic and RTS/CTS. We have considered number of nodes and transmission probability to compute the delay for both the modes. The results show that the performance of RTS/CTS mode is better than the basic access mode. In this paper, we have numerically analyzed the IEEE 802.11 DCF by varying different parameters (i.e. number of nodes, transmission probability etc.).

Keywords- Medium Access Control, Distributed Coordination Function, Markov chain, Delay analysis

I. Introduction

Wireless connectivity is becoming very popular now a days as compared to the other technology i.e. wired technology. Despite of the high speed data transfer rate of Wireless Local Area Networks (WLAN), the wireless connectivity covers limited geographical area. The wireless communication capability allows the devices stay connected even they are mobile. These devices include palmtop computers, personal digital assistants (PDAs), portable computers, digital cameras and printers. This paper focuses on the delay analysis of the MAC protocol of IEEE 802.11 protocol.

The wireless LANs at the physical layer level has more complexity in terms of design, because of the presence of hidden terminals or capture effect. The IEEE 802.11 standard used as WLAN have basic access protocol Distributed Coordination Function (DCF) and an optional Point Coordination Function(PCF). DCF is a asynchronous data transmission function, in this mode of transmission IEEE 802.11 can be used Ad hoc Network. Ad hoc network is infrastructure less network. The other mode PCF is used in infrastructure network and for the transmission of delay sensitive data.

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The RTS/CTS scheme available in IEEE 802.11 helps to combat the hidden terminal problem [4]. The influence of hidden terminal problem has also been discussed in [6-7] along with capture effect. In references [7-9, 18,20] the performance evaluation of 802.11 has been carried out by means of analytical models with simplified Backoff, by employing a two dimensional Markov chain analysis. Bianchi [10] presents an easy systematic model to work out the saturation throughput performance assuming a finite number of stations and ideal channel conditions. Chatzimisios et al.[12] have analyzed throughput and delay of IEEE 802.11 DCF, further they have discussed the results for throughput but not for delay. The authors have analyzed the throughput with modified Binary Exponential Backoff (BEB) of IEEE 802.11 DCF [21]. In [19], a reservation based collision aware method has been used to improve the performance of the IEEE 802.11.

The paper is organized as follows: Section II discusses the working of Distributed coordination function of 802.11 MAC protocol and includes both basic access and RTS/CTS mechanism. Section III reviews the protocol presented in [12]. Section IV discusses the delay analysis results of DCF mode for both basic access and RTS/CTS mechanisms. Finally, section V concludes the paper and presents future work.

II. Distributed Coordination Function

The basic service set (BSS) is the primary building block of IEEE 802.11 WLANs. The area covered by BSS is called basic service area (BSA), just like a cell in cellular network. IEEE 802.11 supports both the ad hoc network and infrastructure network architecture.

The distributed coordination function (DCF) mode is a random access scheme and it is based on the carrier sense multiple access with collision avoidance (CSMA/CA) protocol. DCF consists two ways of transmission, among them one is basic access method and another method which is optional is called RTS/CTS method. The working of each method of medium access is explained below [15].

A. Basic access method

In this method the access to medium is controlled by the inter-frame space (IFS) time period between the transmission of frames. Inter-frame spacing refers to the time interval between the transmission of two successive frames by any station. There are four types of IFS: SIFS, PIFS , DIFS and EIFS, in order from shortest to longest. The IFS with shortest length has highest priority to access the medium, because the wait time to access the medium is lower. SIFS and DIFS are used for ad hoc network and PIFS for infrastructure network. After a SIFS only ACKs, CTS and data frames may be sent. The time interval after an idle DIFS is slotted and a station can transmit only at the beginning of a slot. The size of each slot is ,σ, which is equal to the time needed by any station to detect the transmission of a packet from any other station.

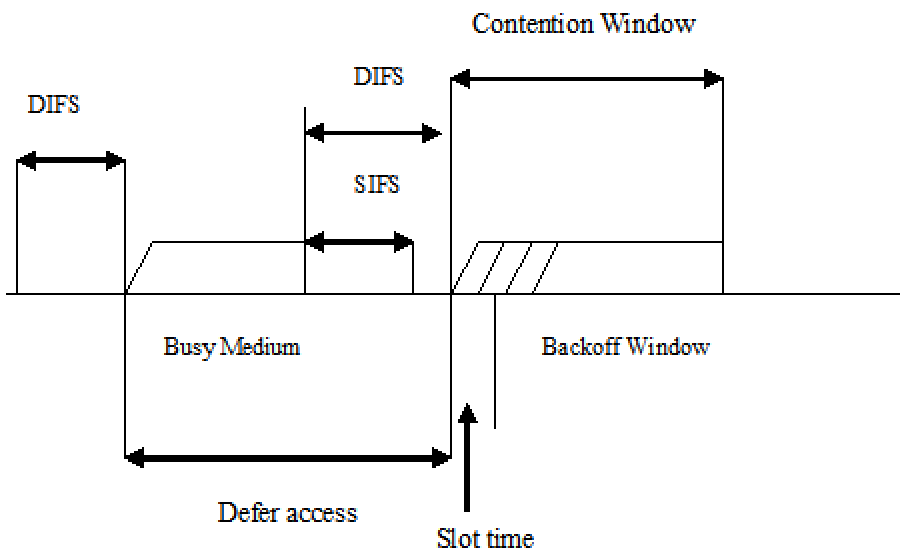

Fig. 1 Basic access mechanism in DCF

If the medium is sensed to be idle for a duration of DIFS, the node accesses the medium for transmission. If the medium is busy, the station defers until a DIFS is detected and then generate a random Backoff period before transmitting. The Backoff period is uniformly chosen within a contention window (CW). The contention window (CW) depends on the number of transmissions failed for the packet. At the first transmission attempt, CW is set equal to CW_{min} which is called minimum contention window. After each retransmission due to a collision, CW is increased as $(\sqrt{2}CW)$ for m'=4, after four retrials the size of contention window is doubled upto a maximum value $CW_{max} = 2^m.CW_{mid}$.

B. The RTS/CTS access method

The transmission of packets in WLAN is based upon CSMA/CA, because of CSMA/CA technique a source station can not hear its own transmission, thus collision takes place. Instead of transmitting a whole data packet of large size, small size control frames are transmitted in the form of RTS/CTS frames. RTS/CTS control frames can be used by a station to reserve channel bandwidth before the transmission of actual data packets. The sender node first transmits the RTS control frame to the receiver. The RTS frame contains the information about the expected duration of whole data transmission. After receiving RTS frame the receiver responds with the CTS control frame, after an SIFS idle period has elapsed. Station hearing the RTS or CTS frame read the duration field and update their network allocation vector (NAV) accordingly. Source station is allowed to transmit its packet only if it receives the CTS correctly. This updation of NAV(from the information) RTS/CTS frame of the neighboring stations helps to combat the hidden terminal problem [16-17].

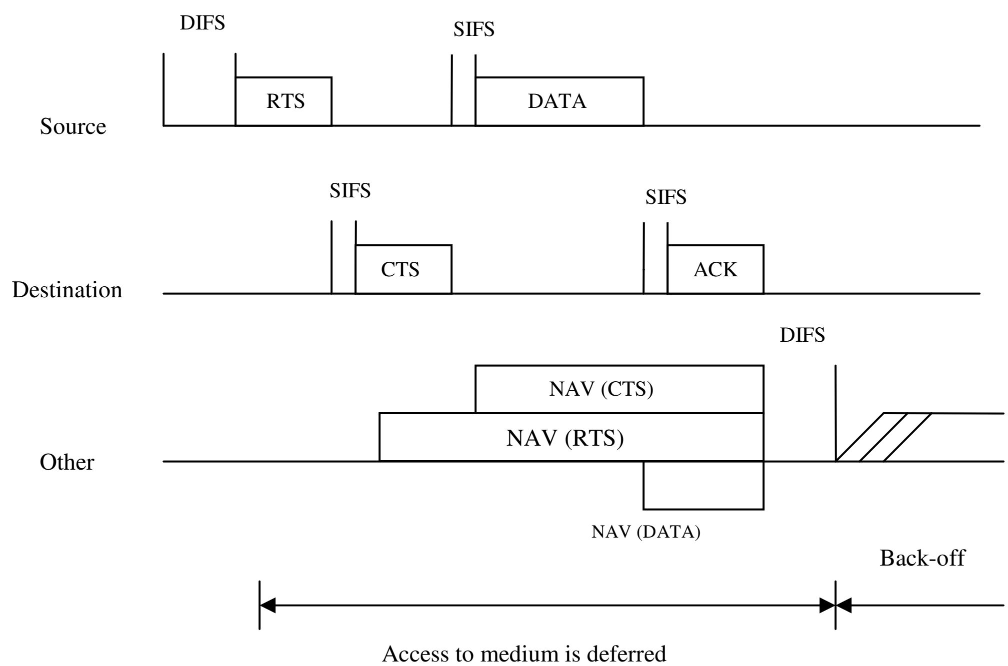

Fig.2 RTS/CTS access mechanism in DCF

Assumptions

Backoff algorithm in IEEE 802.11 is to minimize collisions during contention between multiple stations. Following assumptions are being made for the new modified backoff algorithm for IEEE 802.11.

1. There are collisions because of busy medium.
2. Whenever collision takes place for the resolution of the collision the backoff time to be selected from [0, CW-1] randomly.
3. The size of contention window is between ($CW_{\min}, CW_{\max}$).
4. Initial value of CW is set as $CW_{\min}$.
5. Initially the contention window is modified in the form of $(\sqrt{2}CW)$ then after four collisions at the 5th collision the size of contention window will be doubled in consecutive collisions.
6. The value of contention window (CW) will be set again after each successful transmission or CW reaches the maximum limit of transmission i.e. retry limit. This is the modified Binary Exponential Backoff algorithm.

III. PERFORMANCE ANALYIS FOR DCF

Initially if the collision is low then the size of window is increased in $\sqrt{2}$ factor. As the number of collisions will increase, it will indicate that the numbers of contending nodes are more. In this case the size of contention window will be increased by the factor 2 at every subsequent collision. The value of CW depends on the number of failed transmissions of a frame.

A. Markov Chain Model

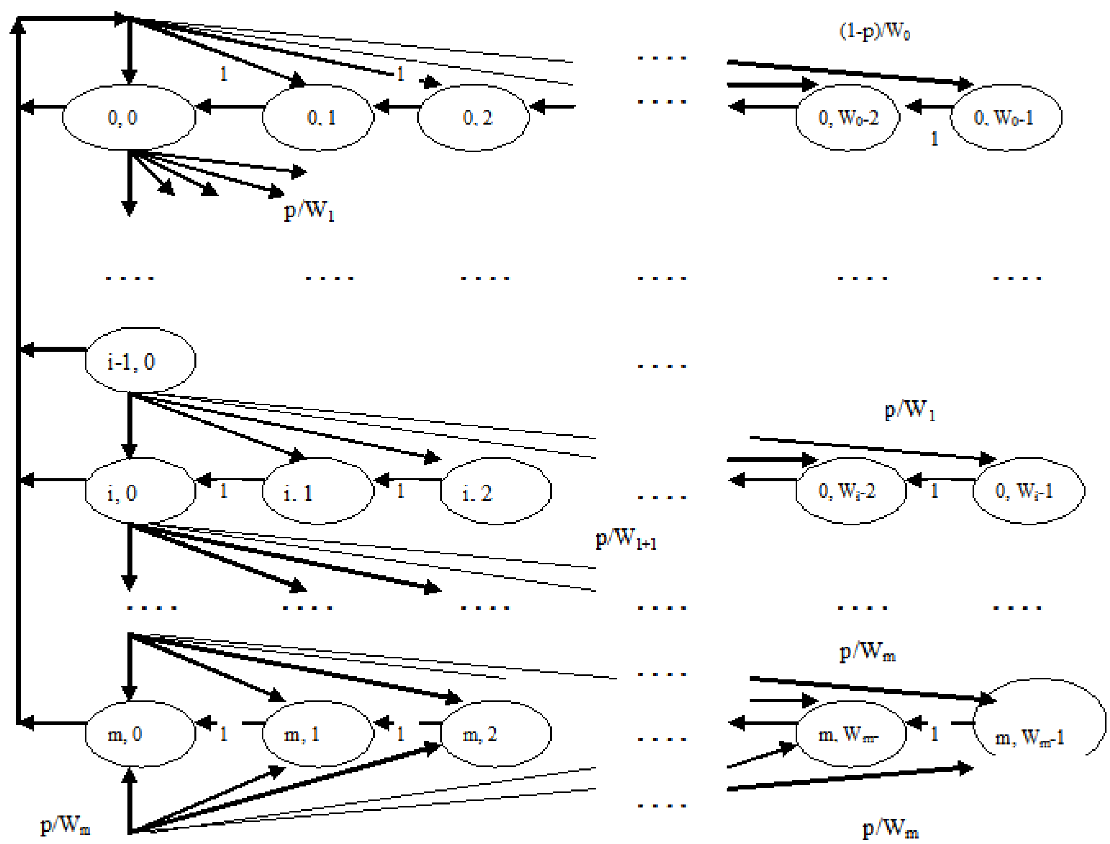

Fig 3 Markov Chain model for the IEEE 802.11 backoff window size

Transmission Probability

Let $b(t)$ be the stochastic process representing the backoff time counter and $s(t)$ be the stochastic process representing the backoff stage for a given station at slot time t. The bidimensional process $\{b(t), s(t)\}$ can be modeled with a discrete-time Markov chain given in the figure .

Let $b_{i,k} = \lim_{t\to\infty} P\{s(t) = i, b(t) = k\}, i \in (0,m), k \in (0, W_i - 1)$ be the stationary distribution of the chain then we can calculate the probability $b_{i,k}$. We have the following relations:

$$b_{i,0} = p.b_{i-1,0}, \quad 0 < i \le m \qquad (1)$$

$$b_{i,0} = p^i.b_{0,0}, \quad 0 \le i \le m \qquad (2)$$

$$W_i = \sqrt{2}.W \qquad i \le m'$$

$$W_i = 2^{m'}.W \qquad i > m' \qquad (3)$$

Where m represents the station short retry count and is equal to 7 according to IEEE 802.11 standard. Owing to the chain regularities, for each $k \in (1, W_i - 1)$, it is

$$b_{i,k} = \frac{W_i - k}{W_i} \cdot \begin{cases} (1-p).\sum_{j=0}^{m-1} b_{j,0} + b_{m,0} & ,i=0 \\ p.b_{i-1,0} & 0 < i \le m \end{cases} , \qquad (4)$$

Using (2),(4) the simplified form will be as:

$$b_{i,k} = \frac{W_i - k}{W_i} b_{i,0} \quad i \in (0,m), \quad k \in (1, W_i - 1). \qquad (5)$$

Thus, by relations (2) and (5) all the $b_{i,k}$ values can be expressed as function of $b_{0,0}$ and of collision probability p. By imposing the normalization condition and some simplification, we have:

$$1 = \sum_{k=0}^{W_i-1} \sum_{i=0}^{m} b_{i,k} = \sum_{i=0}^{m} b_{i,0} \sum_{k=0}^{W_i-1} \frac{W_i - k}{W_i} = \sum_{i=0}^{m} b_{i,0} . \frac{W_i + 1}{2}$$
$$= \frac{b_{0,0}}{2} \left[W \left(\sum_{i=0}^{m'} \left(\sqrt{2}p\right)^i + \sum_{i=0}^{m'} p^i \right) + \sum_{i=m'}^{m} 2^{m'} p^i W \right]$$

From which

$$b_{0,0} = \frac{2.(1-\sqrt{2}p)(1-p)}{W.(1-(\sqrt{2}p)^{m+1}.(1-p) + (1-\sqrt{2}p)(1-p^{m+1})} \qquad ,m \le m'$$
$$= \frac{2.(1-\sqrt{2}p)(1-p)}{W.(1-(\sqrt{2}p)^{m+1}.(1-p) + (1-\sqrt{2}p)(1-p^{m+1}) + W.2^{m'}.p^{m'+1}(1-\sqrt{2}p)(1-p^{m-m'})} \qquad ,m > m'$$

The probability of transmission τ, in a randomly chosen slot can be expressed as

$$\tau = \sum_{i=0}^{m} b_{i,0} = \frac{1-p^{m+1}}{1-p} b_{0,0} \qquad (8)$$

Where $b_{0,0}$ can be expressed as in equation (7) .

The transmission probability τ depends on the conditional collision probability p, which is derived next. The probability p is the probability that at least one of the n-1 remaining stations transmit in the same slot. If all stations transmit with probability τ, the collision probability p is:

$$p = 1 - (1-\tau)^{n-1} \qquad (9)$$

Equations (8) and (9) form a nonlinear system with two unknown variable τ and p, which can be solved by numerical results. Note that we must have $p \in (0,1)$ and $\tau \in (0,1)$.

B. Delay analysis

Let P_{tr} be the probability that there is at least one transmission in the considered slot time. For n contending stations for the network, P_{tr} is given by:

$$P_{tr} = 1-(1-\tau)^n \tag{10}$$

The probability P_s for a successful packet transmission is given by the probability that exactly one station transmits and the remaining n-1 stations defer transmission, conditioned on the fact that at least one station transmits:

$$P_s = \frac{n.\tau.(1-\tau)^{n-1}}{1-(1-\tau)^n} \tag{11}$$

Now we are able to express the delay E[X] as given in [12]:

$$E[D] = E[X]\cdot\sigma + E[N_{Fr}]\cdot(P_S\cdot T_S) + (1-P_S)\cdot T_C) + T_S \tag{12}$$

Where $E[N_{Fr}]$ is the mean number of times a station freezes its counter due to other transmissions before successfully transmitting a frame, σ is the size of a time slot and the time period E[X] that is required for empty slots before successfully transmitting a frame is given by:

$$E[X] = \sum_{i=0}^{m}(q_i\cdot E[BC_i]) \tag{13}$$

Where q_i is the probability that a station's transmission is in stage i and $E[BC_i]$ is the average Backoff counter value in stage i. Here, T_s and T_c are the average times that the medium is sensed busy due to a successful transmission or a collision respectively. The values of T_s and T_c depend on the channel access mechanism and in the basic access:

$$T_s^{bas} = H + E[P] + SIFS + \delta + ACK + DIFS + \delta$$
$$T_c^{bas} = H + E[P] + SIFS + \delta + ACK\_timeout + DIFS$$

For the RTS/CTS access mechanism, it is:

$$T_s^{rts} = RTS + SIFS + \delta + CTS + SIFS + \delta + H + E[P] + SIFS + \delta + ACK + DIFS + \delta$$
$$T_c^{rts} = RTS + SIFS + \delta + CTS\_timeout + DIFS$$

Where $H = PHY_{hdr} + MAC_{hdr}$.

After collision the colliding stations have to wait for the time equal to ACK_timeout and CTS_timeout.

Finally, the time period E[X] and $E[N_{Fr}]$, expressed in slot times, is equal to:

$$E[X] = \frac{b_{0,0}}{2\tau}\left[\frac{W((1-p)(1-2p)(1-(\sqrt{2}p)m') + (1-\sqrt{2}p)(1-p)(1-(2p)^{m-m'-1} - (1-p^m)(1-\sqrt{2}p)(1-p)}{(1-\sqrt{2}p)(1-p)(1-2p)}\right] \tag{14}$$

$$E[N_{Fr}] = \frac{E[X] - E[Idle]}{E[Idle]} \tag{15}$$

Where E[Idle] is the average number of idle slots before a transmission occurs and is equal to:

$$E[Idle] = \frac{idle}{busy} = \frac{1 - P_{tr}}{P_{tr}} \tag{16}$$

By putting (14), (15) and (16) into (12), the delay can be obtained and the outcome is given in the next section.

IV. Delay Analysis Results

The system parameters shown in the table I are being used for the analysis. The figure 4 below indicates the dependency of delay on the number of stations. The results indicate that the delay is lower for the RTS/CTS access mechanism then the basic access mechanism. The delay is lower for the small size networks for basic as well as RTS/CTS access mechanisms but the delay increases drastically for basic access mechanism for larger network size, as compared to the RTS/CTS access mechanism. For RTS/CTS and basic access mechanisms, the performance of the network is almost steady up to the size of network n=15.

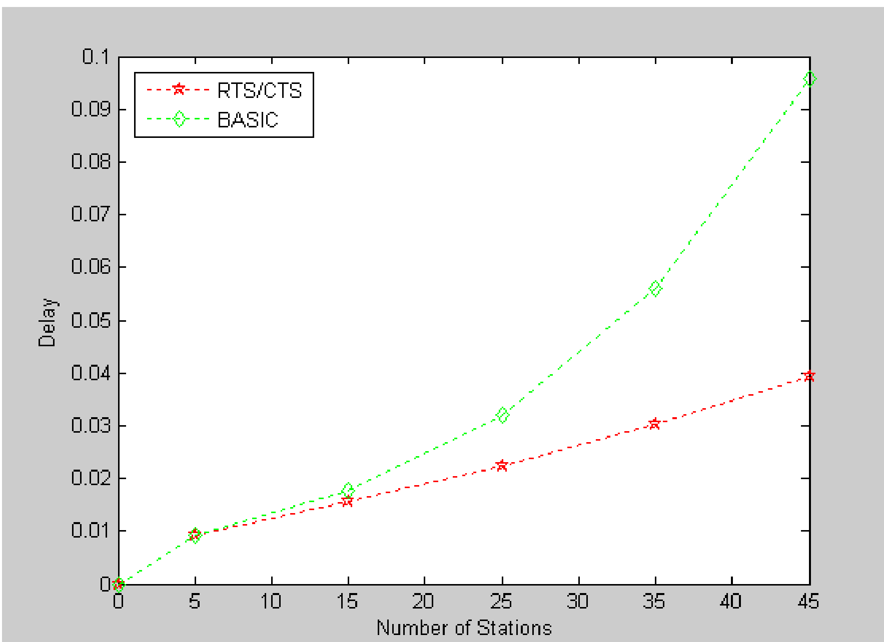

Figure 4 : Delay analysis versus Number of Stations Modified Exponential Backoff method for RTS-CTS and Basic access method

The delay performance of the IEEE 802.11 DCF (RTS/CTS and Basic access method) versus transmission probability has been shown in the figure 5, which indicates that the delay is almost same for both the access methods till the value of transmission probability (tau = 0.82), after that the performance of RTS/CTS is better than basic access method. There is steep rise in delay for basic access method than RTS/CTS method. Figure 6 indicates that the delay increases linearly (nearly) with the size of frame for both the access methods of IEEE 802.11DCF. There is not a considerable difference in terms of delay performance for both the access methods.

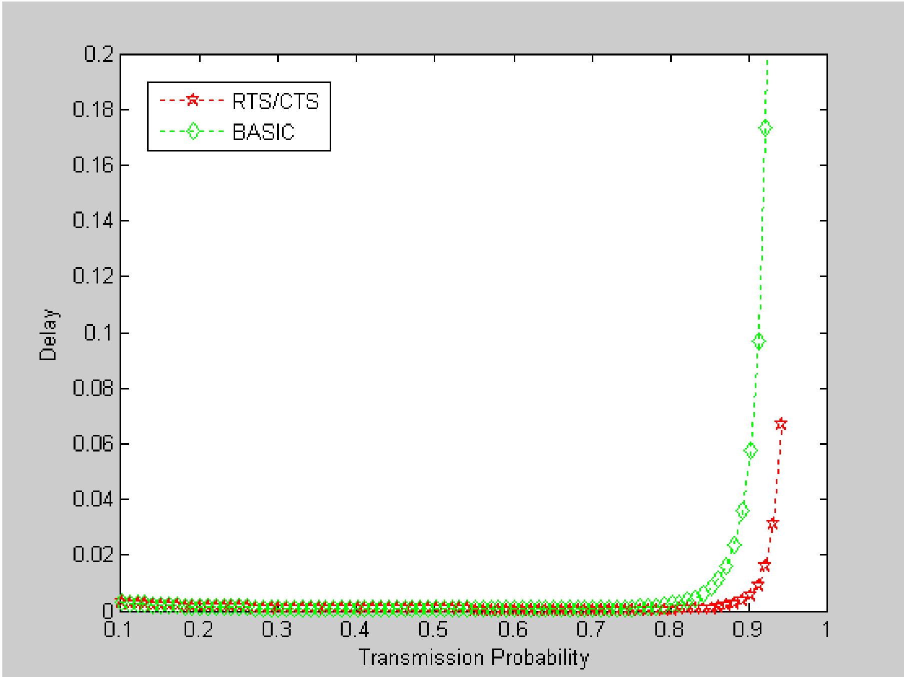

Figure 5 : Delay analysis versus Transmission Probability of Modified Exponential Backoff method for RTS-CTS and Basic access method

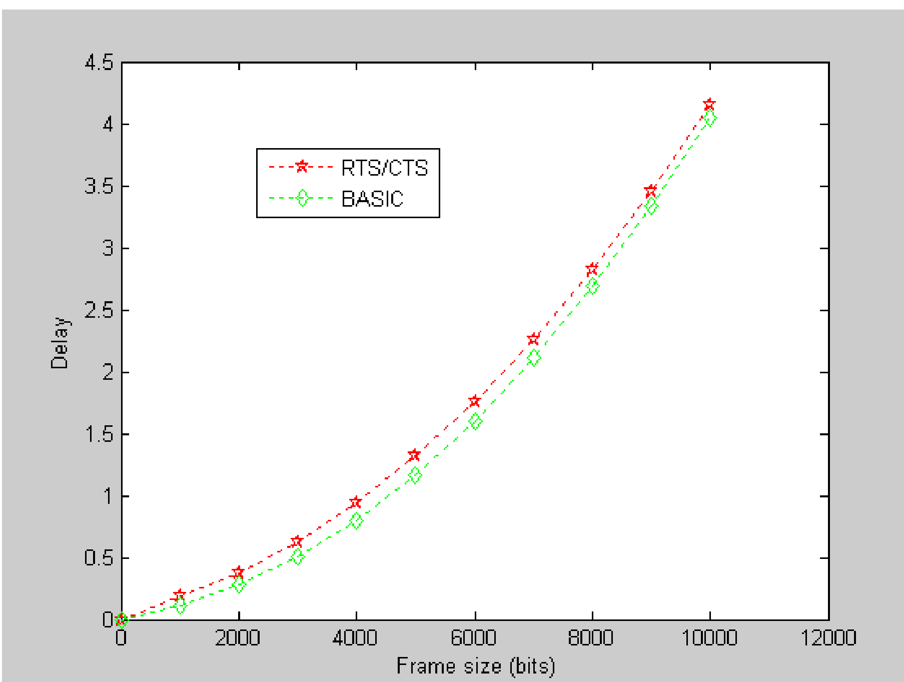

Figure 6 : Delay versus Frame size of Modified Exponential Backoff method for RTS-CTS and Basic access method

TABLE I System Parameters

Transmission Rate	1 Mbps
Packet Payload	8184 bits
PHY header	128 bits
RTS	160 bits + PHY header
CTS	112 bits + PHY header
ACK	112 bits + PHY header
DIFS	128 μs
SIFS	28 μs
Slot Time (σ)	50 μs
Propagation delay (δ)	1 μs
ACK_Timeout	300 μs
CTS_Timeout	300 μs

V. Conclusion

The paper presents a Markov chain based model with modified Exponential Backoff method. This model is used to evaluate the delay based performance of IEEE 802.11, the standard used for wireless LANs. The delay based performance of the IEEE 802.11 MAC protocol with modified Backoff algorithm has been evaluated, with respect to the frame size, network size and transmission probability. For number of stations the delay performance is better for RTS/CTS access method than the basic access method. The model is suitable for both access methods, separately or combined. The performance of both access methods is compared with respect to transmission probability. The performance of RTS/CTS access method is better than basic access method for all considered parameters. The delay of both the access methods is almost similar for frame size. However the performance of RTS/CTS method is far better for large network size.

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