

## PERFORMANCE ANALYSIS OF THE VARIABLE BACKOFF EXPONENTIAL ALGORITHM FOR IEEE 802.11 BASED MOBILE AD HOC NETWORKS

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### Abstract

In this paper, an IEEE 802.11 based mobile ad hoc network (MANET), a network node is accessed by a common wireless channel through the distributed coordinate function (DCF), which is provided at the medium access control (MAC) layer of the IEEE 802.11 standard. In this paper, a history based adaptive backoff exponential algorithm is used, through which we can find packet collision probability, average contention window, average number of backoff and average time delay. Moreover we have to find the optimal value of packet collision probability, average contention window, average number of backoff and average time delay with respect to number of nodes using a developed mathematical model.

**Keywords:** IEEE 802.11 standard, History based adaptive backoff (HBAB), Mobile ad hoc networks.

### Introduction

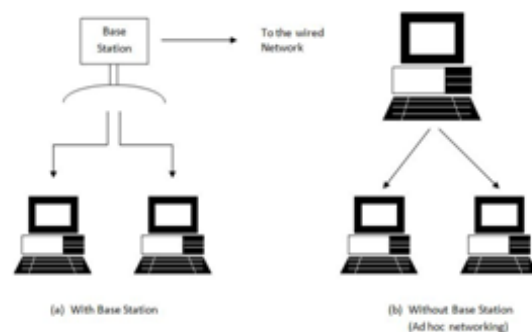
Wireless LAN's have become more and more popular since they can satisfy the requirements such as mobility, relocation of user, ad-hoc networking and coverage of locations that are quite difficult to wire. Earlier, the wireless LAN's were costly, could support only low data rates, a license was required. Because of all these factors, there were limitations on the practical utility of wireless LAN's. However, all these problems have been addressed now which is increasing the popularity of wireless LAN's day by day.

Wireless LAN is a latest example uses wireless communication. Devices such as workstations laptop, laptop, computers, cordless telephones and other communication appliances share the wireless medium such as 5 GHz radio or infrared light.

Wireless network access of mobile devices such as smart phones and laptops has recently become more feasible and popular due to the incredible developments in wireless technologies, with IEEE 802.11 Wireless Local Area Networks (WLANs) being one of the most implemented standards. Since the wireless medium is shared by all transmitting stations in range, IEEE 802.11 has to control medium access among contending stations so as to minimize the effect of collisions on the performance of the network. [1]

In wireless LAN, each computer and note book computer is equipped with a short range transmitter and receiver to allow communication between them. The IEEE committee standardized the wireless LAN and the standard was 802.11. Actually, this standard had to work in following two different methods:  
In the presence of a base station,

In the network with the base station, all the communication passes through the base station that is also known as the access point in 802.11 terminologies. In the network without base station, the computers shall communicate between each other. This mode is also known as Ad hoc networking.



**Fig1: illustration of wireless networks (with or without base station)**

The IEEE 802.11 standard specifies the physical layer and medium access control layer of a wireless local

area network. At the medium access control (MAC) layer, positive acknowledgement (ACK) is used to achieve reliable delivery of data packets between network nodes. The receiver of a data packet has to transmit an acknowledgement (ACK) to the sender of the packet if it receives the packet successfully. [2]

HISTORY BASED ADAPTIVE BACK OFF

History Based Adaptive Back off (HBAB) algorithm is that, in which the history of the past trials for transmission is consider. The HBAB algorithm checks the last N states of the medium and decides whether to increment or decrement the contention window size value based on the channel's tendency to being free or busy. In other words, if the channel tends to be free (the most recent state(s) indicate(s) a free channel), then the CW value is decreased; if the channel tends to be busy (the most recent state(s) indicate(s) a busy channel), then the CW value is increased. The HBAB algorithm have fix parameter, multiplicative factor ( $\alpha$ ) which are used to increase or decrease the new CW based on the old CW value (that will automatically increase or decrease the back off time). [4]

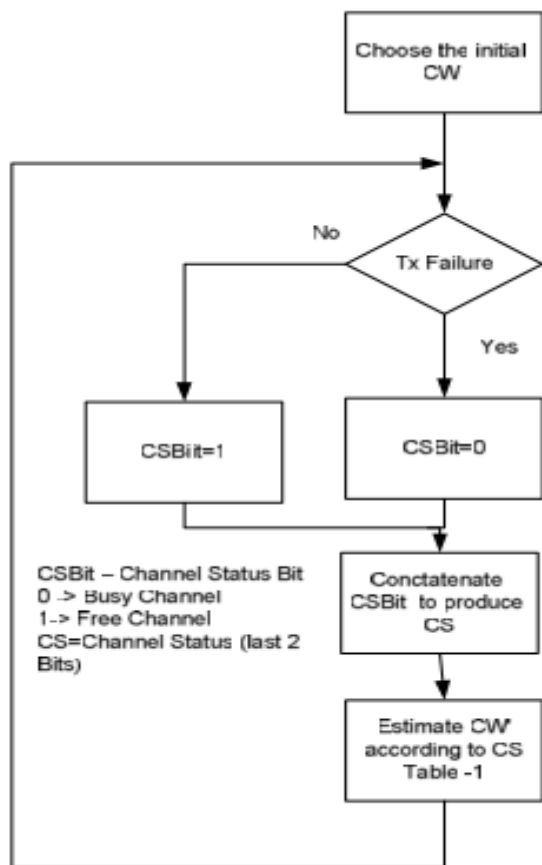


Fig2: Flowchart of History based Adaptive backoff

DISTRIBUTED COORDINATE FUNCTION

In the 802.11 protocol, the fundamental mechanism to access the medium is called distributed coordination function (DCF). This is a random access scheme, based on the carrier sense multiple access with collision avoidance (CSMA/CA) protocol. Retransmission of collided packets is managed according to binary exponential back off rules. The standard also defines an optional point coordination function (PCF), which is a centralized MAC protocol able to support collision free and time bounded services. [5]

According to the DCF mechanism, whenever a station has a packet to send it should defer its transmission for a guard period known as the distributed inter frame spacing time (DIFS), during which the channel must be sensed idle. This is followed by a random back off interval. Back off intervals are slotted, and stations are only permitted to commence their transmissions at the beginning of slots. When back off is initiated, a random integer back off time is selected from the range  $[0; CW - 1]$  with a uniform distribution, where CW is a contention window. As the first transmission attempt, CW is set equal to  $CW_{min}$ , the minimum contention window. The back off time counter is decremented as long as the channel is sensed idle. It is frozen when activities (i.e. packet transmissions) are detected on the channel, and reactivated after the channel is sensed idle again for a guard period. This guard period is equal to a DIFS if the transmitted packet was error-free, and equal to the extended inter frame spacing time, EIFS, if there was a collision. The station transmits its packet when the back off time counter reaches zero. Collision occurs when the counters of two or more stations reach zero in the same slot. [5]

The following aspects are used in this analysis:

- 1) A mathematical model is used for deriving the packet collision probability of a node, the backoff probability distribution of a node, the average number of backoff's of a node, the average size of a contention window, and the average packet delay.
- 2) This mathematical model is based on the assumption that the transmission queue of each node is always nonempty.
- 3) An optimal value of initial contention window size is used to avoid the large gap between the minimum

and maximum contention window size and thus maximize the utilization of the wireless channel.

4) The packet collision probability of a node decreases as the size of the contention window increases when the number of nodes in the network is large. [1]

**MATHEMATICAL ANALYSIS**

An adaptive IEEE 802.11 History Based Adaptive Backoff (HBAB) algorithm to improve quality of service (QoS) is used. The protocol modifies the IEEE 802.11 backoff algorithm, which is used to control the contention window in the case of collisions, in order to provide a better QoS performance according to the network status and condition.

Let minimum and maximum slot numbers in a contention window are 0 and CW, respectively, then the size of a contention window will be equal to CW+1. Let  $L_i$  be the size of the contention window after it is doubled  $i$  times ( $i = 0,1,2, \dots, m$ ), where  $L_0$  is the minimum contention window size, i.e.,  $L_0 = CW_{min} + 1$ , and  $L_m$  is the maximum contention window size, i.e.,  $L_m = CW_{max} + 1$ . Also assumes that there are  $n$  nodes in the network and use  $V$  to denote the set of nodes in the network.

Under CSMA/CA, a node has to sense the wireless channel before its transmission. Let  $G_k$  is the random number of nodes such that

$$\sum_{k=0}^m |G_k| = n \quad (1)$$

Let a node is in state  $i$  if it has continuously performed the BEB algorithm for  $i$  times before a successful transmission. We use node( $i$ ) to denote a node in state  $i$ . Clearly, the contention window size of node( $i$ ) satisfies:

$$L_i = 2^i L_0, \quad i = 0,1,2, \dots, m \quad (2)$$

and

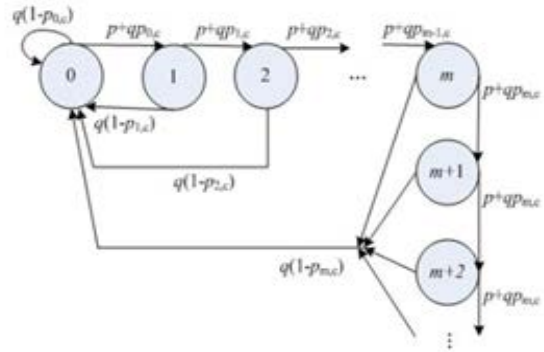
$$L_i = L_m, \quad i = m + 1, m + 2, \dots \quad (3)$$

that means the nodes in states  $0, 1, \dots, \text{and } m - 1$  are included in  $G_0, G_1, \dots, \text{and } G_{m-1}$ , respectively, whereas all the nodes in state  $m, m + 1, m + 2, \dots$  are contained in  $G_m$ .

Let  $p$  be the packet loss probability of the wireless channel and define  $q = 1 - p$ . Let  $p_{i,c}$  be the probability that a packet collision occurs during the packet transmission of node( $i$ ). Obviously, for node  $i > m$ , we have  $p_{i,c} = p_{m,c}$  due to  $L_i = L_m$ .

The following figure gives the state transition diagram of a node, in which a circle stands for a state, an

arrow represents a state transition, and the expression on an arrow is the transition probability corresponding to the event of a state transition. [1]



**Fig3: State transition diagram of nodes**

Let  $p_{i,nc}$  is the probability that node ( $i$ ) transmits without a collision such that  $p_{i,c} = 1 - p_{i,nc}$  i.e. none of the other nodes in the network picks the same backoff slot as the one node( $i$ ) picks.

Here the state diagram shows that at state '0', there is no collision so probability of non-collision i.e.  $p_{0,nc} = 1 - p_{0,c}$  is used at 0<sup>th</sup> state. At the same time there is no loss of packet so the probability that packet does not loss i.e.  $q = 1 - p$  is used. So indirectly at 0<sup>th</sup> node joint probability is  $q(1 - p_{0,c})$ .

At 1<sup>st</sup> state, some portion of packet is loss, so probability  $p$  is used and it is added to mutual probability of packet that does not loss ( $q$ ) and probability of collision at 0<sup>th</sup> state, i.e.  $p_{0,c}$  towards 0<sup>th</sup> to 1<sup>st</sup> node but simultaneously if at 1<sup>st</sup> node no packet does loss and if there is no collision then probability  $1 - p_{1,c}$  is used towards 1<sup>st</sup> to 0<sup>th</sup> state. So final probability at 1<sup>st</sup> node is calculated by  $q(1 - p_{1,c})$ .

This will repeat for  $i \leq m$  (i.e. number of nodes should be less or equal to integer which represent the value that doubles itself to reach maximum contention window) But for  $i > m$ , i.e. at  $m, m + 1, m + 2, \dots$  state,,  $m^{\text{th}}$  state will reach at 0<sup>th</sup> position if and only if they have probability equal to  $q(1 - p_{m,c})$ , due to  $L_i = L_m$ . Similarly  $m^{\text{th}}$  state will move to next if and only if they have probability  $p + qp_{m,c}$  (refer fig5). The same will be continue for all the states having indexes greater than  $m$ . [1]

The following diagram showing the different backoff slots

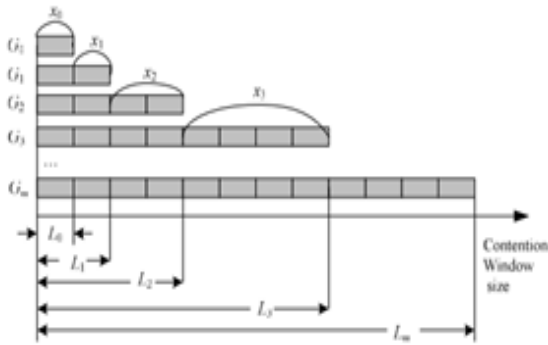


Fig4: Different backoff slots

Let  $x$  be the backoff slot picked by node( $i$ ) with contention window size  $L_i$ , and  $p_{i,nc}(x)$  be the probability that any other node in the network does not collide with node( $i$ ) in slot  $x$ . Clearly, node( $i$ ) randomly picks a slot in the set  $\{0, 1, \dots, L_i - 1\}$  with probability  $1/L_i$ . Thus, the probability that node( $i$ ) picks a particular time slot  $x$  and other nodes do not collide with node( $i$ ) in the time slot is equal to the product of  $p_{i,nc}(x)$  and  $1/L_i$ , which results in the probability that node( $i$ ) transmits without a collision in any picked slot, i.e.,

$$p_{i,nc} = \sum_{x=0}^{L_i-1} \frac{1}{L_i} p_{i,nc}(x) \quad (4)$$

As from the figure6, the interval  $[0, L_i - 1]$  can be divided into the intervals:  $[0, L_0 - 1]$ ,  $[L_0, L_1 - 1]$ ,  $[L_1, L_2 - 1]$  and  $[L_{i-1}, L_i - 1]$ . On the basis of this, equation (4) can be rewritten as

$$p_{i,nc} = \frac{1}{L_i} \left[ \sum_{x=0}^{L_0-1} p_{i,nc}(x) + \sum_{x=L_0}^{L_1-1} p_{i,nc}(x) + \dots + \sum_{x=L_{i-1}}^{L_i-1} p_{i,nc}(x) \right] \quad (5)$$

For any  $x < L_0$ , any node in  $G_j$  collides with node( $i$ ) with probability  $\frac{1}{L_j}$  as each node in  $G_j$  randomly picks a slot in the set  $\{0, 1, \dots, L_i - 1\}$ , which leads to the probability that all the nodes in  $G_j$  do not collide with node( $i$ ) being  $(1 - \frac{1}{L_j})^{|G_j|}$ , where  $j = 0, 1, \dots, m$  and  $j \neq i$ . Particularly, for  $j = i$ , this probability becomes  $(1 - \frac{1}{L_i})^{|G_i|-1}$  because node( $i$ ) is also in  $G_i$ , i.e., there are  $|G_i|-1$  nodes in  $G_i$ , which are likely to collide with node( $i$ ). Thus, the probability that all the nodes in  $G_0, G_1, \dots,$  and  $G_m$  do not collide with node( $i$ ) in slot  $x$  can be calculated as

$$\sum_{x=0}^{L_0-1} p_{i,nc}(x) = L_0 \frac{L_i}{L_i - 1} \prod_{j=0}^m (1 - \frac{1}{L_j})^{|G_j|} \quad (6)$$

Where  $x \in \{0, 1, \dots, L_0 - 1\}$

For  $L_0 \leq x < L_1$ , any node in  $G_0$  does not collide with node ( $i$ ), but each node in  $G_1, G_2, \dots,$  and  $G_m$  collides with node ( $i$ ) with probability  $\frac{1}{L_1}, \frac{1}{L_2}, \dots,$  and  $\frac{1}{L_m}$ , respectively, which produces

$$\sum_{x=L_0}^{L_1-1} p_{i,nc}(x) = (L_1 - L_0) \frac{L_i}{L_i - 1} \prod_{j=1}^m (1 - \frac{1}{L_j})^{|G_j|} \quad (7)$$

Where  $x \in \{L_0, L_0 + 1, L_0 + 2 \dots \dots, L_1 - 1\}$

Similarly for  $L_{m-1} \leq x < L_m$ , any node in  $G_0, G_1, G_2, \dots, G_{m-1}$  does not collide with node ( $i$ ), but each node in  $G_m$  collides with node ( $i$ ) with probability  $\frac{1}{L_2}, \frac{1}{L_3}, \dots,$  and  $\frac{1}{L_m}$ , respectively, which leads to

$$\sum_{x=L_{m-1}}^{L_m-1} p_{i,nc}(x) = (L_m - L_{m-1}) \frac{L_i}{L_i - 1} \prod_{j=m}^m (1 - \frac{1}{L_j})^{|G_j|} \quad (9)$$

Where

$x \in \{L_{m-1}, L_{m-1} + 1, L_{m-1} + 2 \dots \dots, L_m - 1\}$

Now from Eq (4) and (9), we can write,

$$p_{i,nc} = \frac{1}{L_i - 1} \sum_{k=0}^i \left( (L_k - L_{k-1}) \prod_{j=k}^m (1 - \frac{1}{L_j})^{|G_j|} \right) \quad (10)$$

As  $p_{i,c} = 1 - p_{i,nc}$  so we can write,

$$p_{i,c} = 1 - \frac{1}{L_i - 1} \sum_{k=0}^i \left( (L_k - L_{k-1}) \prod_{j=k}^m (1 - \frac{1}{L_j})^{|G_j|} \right) \quad (11)$$

Let  $P_i$  be the probability that a node is in state  $i$  ( $i = 0, 1, 2 \dots$ ). Thus, we have

$$\sum_{i=0}^{inf} P_i = 1. \quad (12)$$

Now from figure 3, the probability of a node is in 1<sup>st</sup> state can be written as following:

$$P_1 = P_0 [p + (1 - p)p_{0,c}]$$

The above equations define that the probability is in node 1 in terms of packet loss probability and packet collision probability at 0<sup>th</sup> state. i.e. when a node moves from 0<sup>th</sup> state to 1<sup>st</sup> state, it has probability  $P_0 [p + qp_{0,c}]$ . Similarly moving from 1<sup>st</sup> to 2<sup>nd</sup> state, probability will be  $P_1 [p + qp_{1,c}]$ , and so on.

$$P_m = P_{m-1} [p + (1 - p)p_{m-1,c}]$$

$$P_{m+1} = P_m [p + (1 - p)p_{m,c}] \quad (13)$$

$$P_{m+i} = P_0 [p + (1 - p)p_{m,c}]^i \prod_{j=0}^{m-1} [p + (1 - p)p_{j,c}]$$

$$\Rightarrow \sum_{i=0}^{inf} P_{m+i} = P_0 \frac{1}{(1 - p)(1 - p_{m,c})} \prod_{j=0}^{m-1} [p + (1 - p)p_{j,c}] \quad (14)$$

Now using Eq 12-14, we can obtain the value of  $P_0$ , i.e.

$$P_0 = \left( 1 + \sum_{i=0}^{m-2} \prod_{j=0}^i [p + (1-p)p_{j,c}] + \frac{1}{(1-p)(1-p_{m,c})} \prod_{j=0}^{m-1} [p + (1-p)p_{j,c}] \right)^{-1} \quad (15)$$

From the Eq (10), (12), (14) & (15), we can obtain the average contention window size of a node, i.e.

$$L_{avg} = \sum_{i=0}^{m-1} L_i P_i + \sum_{i=0}^{inf} L_m P_{m+i} \quad (16)$$

Similarly the average number of backoff's before a successful transmission is given by,

$$N_{backoff} = \sum_{i=1}^{inf} i P_i \quad (17)$$

Let  $\tau$  be the duration of a time slot, thus the average delay for a node to successfully transmit a packet is

$$T_{delay} = \frac{L_{avg} - 1}{2} \tau \quad (18)$$

PERFORMANCE ANALYSIS

In this analysis, we have assumed some following assumptions that the minimum and maximum contention window size is let 16 and 1024 respectively. Also simultaneously we are comparing the value of average contention window size, average back off and average time delay with for different probabilities as 0.1, 0.4, 0.7 and 0.9 respectively.

We have considered  $|G_0|, |G_1|, |G_2|, \dots, |G_m|$  as random variables because each node picks its time slot randomly considering the following equation;

$$|G_0| + |G_1| + |G_2| + \dots + |G_m| = n \quad (19)$$

If the number of nodes in a network is too small, it does not easy to visualize the performance of the variable back off exponent algorithm. This is because in that case the probability that two or more nodes pick the same time slot that leads to a packet collision would be very small and as a result the contention window size of a node could rarely be alpha times to reach the maximum i.e.  $CW_{max}$ .

Under all assumptions, we obtain the different graphs for different value of multiplicative factor over 1000 runs with each random probability  $|G_i|$ , satisfying the above equation (19).

The graphs with different values of multiplicative factor (i.e.  $\alpha=1.4$ ,  $\alpha=2$  and  $\alpha=2.4$ ) of packet collision probability, average packet length, average number of backoff's and average time delay showing the probability of packet collision with respect to number of nodes.

Fig 5-7, represents the variation of packet collision probability v/s node states for various multiplicative factors.

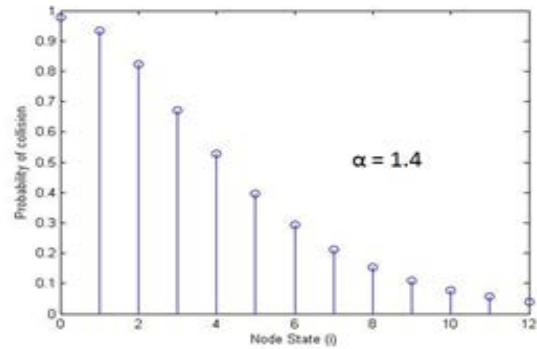


Fig5: packet collision probability v/s node state(α=1.4)

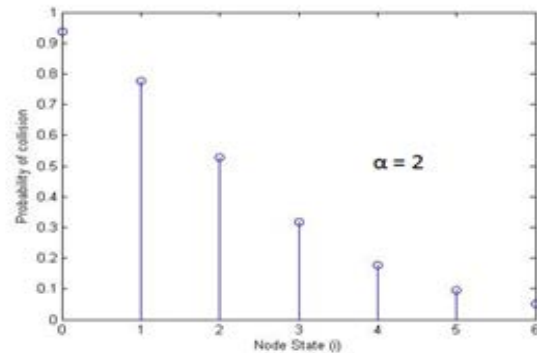


Fig6: packet collision probability v/s node state(α=2)

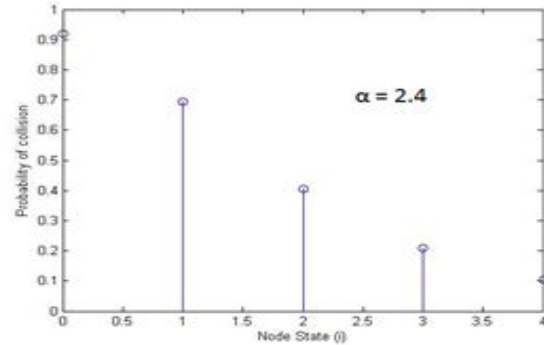


Fig7: packet collision probability v/s node state(α=2.4)

The above figure 5-7 represents the variation of packet loss v/s node states, as the number of nodes increases, the packet loss probability decreases and the multiplicative factor increases, the number of nodes decreases. This is because as the multiplicative factor decreases, it increases its value, till it does not reach the maximum contention window, thus number of nodes increases and vice versa.

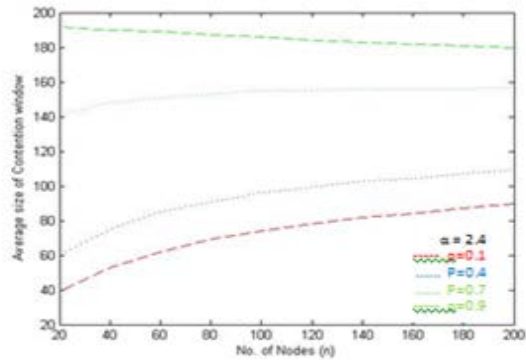
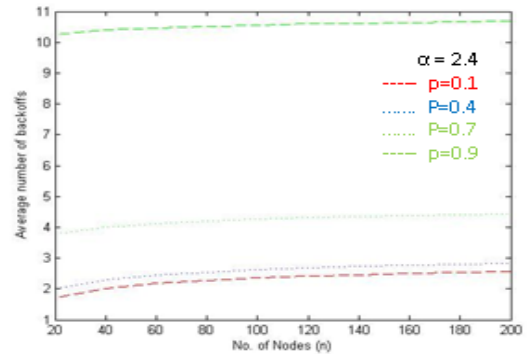
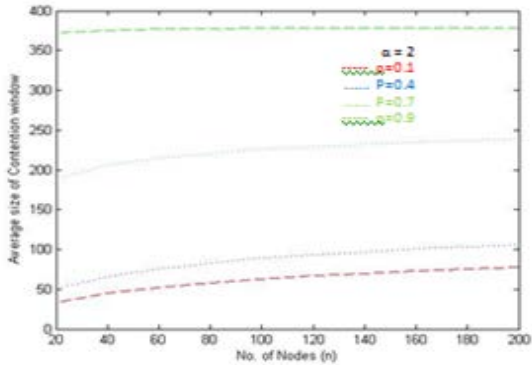
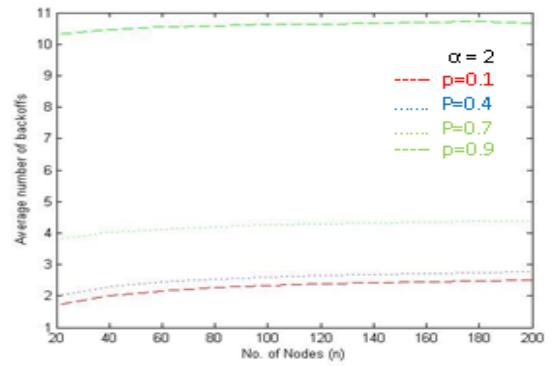
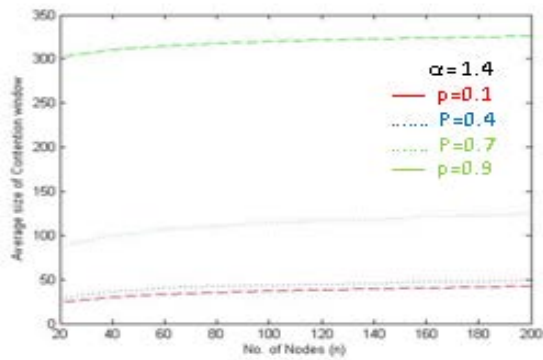
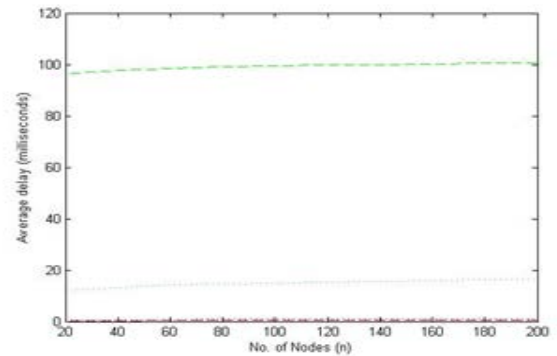
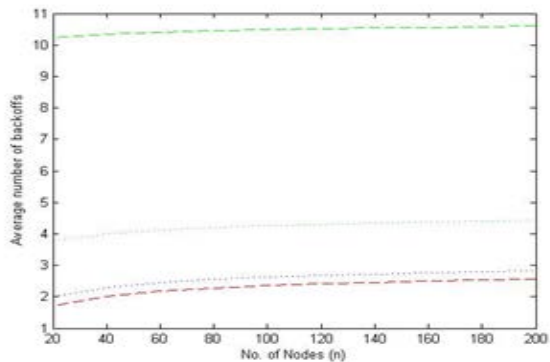


Fig 11-13: Average number of backoffs v/s number of nodes.

Fig8-10: average contention window size v/s number of nodes

Figure 8-10 represents the variation of average contention window size v/s number of nodes for the different multiplicative factor. From figures, we seen that as the probability increases

The above figure 11-13 represents the variation of average number of backoff's v/s number of nodes, as the number of nodes increases, the average backoff number decreases and the multiplicative factor increases, the number of nodes decreases. This is because as the multiplicative factor decreases, node increases its value, till it does not reach the maximum contention window, thus number of nodes increases and vice versa. In other words we can say that as the multiplicative factor increases, number of nodes decreases, but simultaneously packet collision probability increases, this increases backoff number.



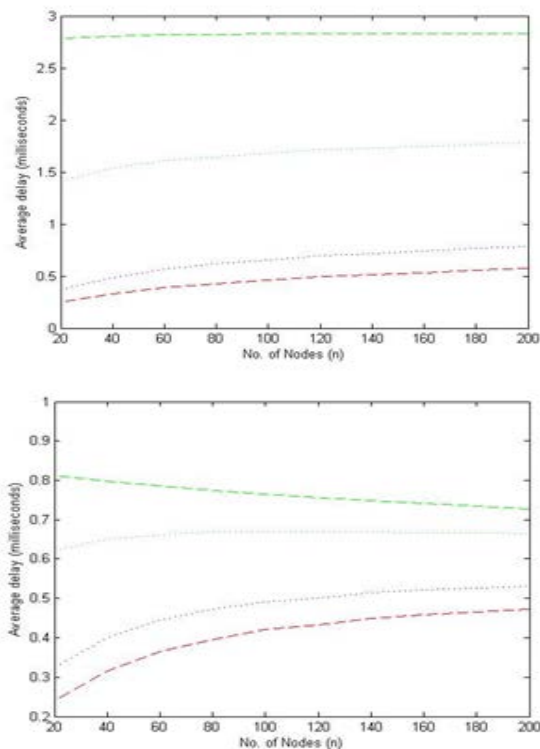


Fig 14-16: Average time delay v/s number of nodes.

The above figure 14-16 represents the variation of average time delay v/s number of nodes, as the number of nodes increases, the average time delay decreases and the multiplicative factor increases, the number of nodes decreases. This is because as the multiplicative factor decreases, it increases its value, till it does not reach the maximum contention window, thus number of nodes increases and vice versa. In other words we can say that as the multiplicative factor increases, number of nodes decreases, but simultaneously packet collision probability or time delay increases.

**RESULT**

IN MOBILE AD HOC NETWORKS, A NODE TRANSMITS IT PACKET LENGTH ON THE BASIS OF CONTENTION WINDOW SIZE, PROBABILITY OF PACKET COLLISION AND THE PROBABILITY THAT A NODE PRESENT IN N<sup>TH</sup> STATE FOR CAPTURING THE A WIRELESS CHANNEL. THE VARIABLE BACKOFF EXPONENTIAL ALGORITHM IN THE IEEE 802.11 PLAYS AN IMPORTANT ROLE THOROUGH WHICH PACKET COLLISION CAN BE AVOIDED AND A IMPROVED CHANNEL OR UTILIZED CHANNEL CAN BE ACHIEVED.

We have used three different value of multiplicative factor ( $\alpha$ ) i.e 1.4, 2 & 2.4 and analysed different plots of packet collision probability with respect to node state, average contention window size, average number of backoff's and average time delay with

respect to number of nodes and found that all these parameters like average contention window size, average number of backoff's and average time delay increases linearly with number of nodes while the packet collision probability decreases with node states. This is because on moving to a higher state or larger contention window size, the probability that a packet has lost is decreased.

Simulation experiment is performed by using MATLAB, in which we assumed that n=200 and each simulation result was averaged over 1000 runs.

**CONCLUSION**

In this analysis, a variable backoff exponent is used to improve the performance of IEEE 802.11 that can be used in mobile Ad hoc networks to achieve the lower delay and low packet collision probability i.e. better packet delivery fraction. On observing all the graphs, we can conclude that the when the network congestion increases, the contention window size corresponding to network size simultaneously increases. Also at the same time average number of backoff's as well as average time delay also increases with number of nodes.

In addition, we can also conclude that as the number of nodes increases, the packet collision probability of a node decreases as the size of contention window is multiplicative times changed. In this algorithm each packet collides with constant and independent probability at the each transmission of packet and regardless of the number of nodes the retransmission of collided packets occurs. But this is not true for small number of nodes, as packet collides; it increased its collision probability or average contention window size value multiplicative factor ( $\alpha$ ) times to achieve the maximum contention window size. Or in other words, this is not true because probability that the two or more nodes pick the same backoff time slot is very small that causes the widow size approximate doubled.

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