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Double Back-off in OFDMA-ALOHA

Chandan Singh Ujarari[1], Arun Kumar[2]
[1]*Department of mathematics statistics and computer science*
[2]*G. B. Pant University of Agriculture & Technology, Pantnagar, India*

Abstract: In aloha protocol collision occurs when there is no success and packet stay in back-off state. In an attempt to reduce the packet collisions and achieve faster retransmission, OFDMA-Aloha analysis is used. In this paper the analysis is carried out with double back-off states for retransmission in two blocks in order to get more retransmission to reduce the packet collisions. Accordingly packet moves in either first block or in the second. We analyze two protocols (Aloha and double back-off in OFDMA-Aloha) under the same total bandwidth and load conditions. First of all we derive the exact distribution of the OFDMA-Aloha which consists of double back-off to the saturated case then we will discuss the delay analysis for single channel Aloha and for double back-off in OFDMA-Aloha. When the gap between the number of channels and the number of users is large, OFDMA-Aloha with double back-off performs better than single channel Aloha.
Keywords: OFDMA, Aloha, multi-channel MAC, fast retrial algorithm, Queuing theory.

I. INTRODUCTION

For data transmission, OFDMA principle is to utilize orthogonal subcarriers in frequency. OFDMA is used in IEE 802.16 (WiMax) and LTE (long term evaluation) allocates a number of time/frequency resources to specific users. A sub-band comprises several sub-carriers. If the sub-carriers and symbols are permuted in frequency and optionally in time, over the carrier frequency the data is moved, such that frequency variety is exploited and it can reduces the probability that a whole data block is dropped due to frequency selective fading or interference in a sub- band. In OFDMA there is frequencies sub-carriers are orthogonal and multiple sub-carriers are modulated by single source of data. Multiple users are allowed to access different sub-bands simultaneously since total bandwidth is divided into many channels by accumulating OFDM sub-carriers into sub-bands (sub-channels). An example of this channelization is done in LTE by grouping 12 OFDM sub-carriers into a 180 kHz sub-channel which gives about 100 sub-channels in a 20 MHz channel. This is in contrast to IEEE 802.11a/g wireless LANs which are also based on OFDM, but only give access to the whole 20 MHz channel to one user at a time. According to the nature of OFDMA, different sub-channels is switched instantaneously. The channels instantaneous and sub-channels orthogonality create a new degree of freedom to the MAC layer. The controlling of access to all sub-channels within the cell and coordinates with adjacent cells in order to limit intercellular interference is done by base station, in OFDMA cellular networks. However, this concept for emerging heterogeneous networks where small cells like femtocells are expected to play an important role in increasing the capacity and offloading traffic of the network is not appropriate. In a small indoor area femtocells are intended to serve few users and consist of a small access point. Centralized frequency planning and coordination becomes a challenging task since femtocells are deployed in ad-hoc locations by end users and appear/disappear frequently. In an OFDMA network most of the time a femtocell is served by a single user while a cluster of adjacent femtocells can be essentially thought of as multiple users competing for all available sub-channels. Random access protocols are spontaneously preferred in such conditions and in future dense femtocell deployments are expected to play an important role. Various random access protocols have been proposed for OFDMA networks, see for example [2]–[4]. In [2], the authors proposed an opportunistic multi-channel Aloha in which the transmission probability is adapted which is based on the channel state information in each sub-channel. In [1] the authors proposed Delay Analysis of OFDMA-Aloha. In a distributed manner and compare it to the centralized sub-channel allocation our objective here is to exploit the multi-user diversity. OFDMA Aloha is a direct extension of the single channel Aloha is proposed in [3], the node moves towards the another (randomly selected) sub-channel subject to a maximum retry limit immediately, when a collision occurs in one sub-channel instead of waiting for a random back-off period. The basic idea of [3] extended recently [4] to CSMA/CA systems. In OFDMA CSMA/CA, a node first become aware of all sub-channels, selects one sub-channel randomly and then back-offs for a random Collision Avoidance (CA) period is same to that of the standard procedure in IEEE 802.11. In this paper, we focus on an OFDMA-Aloha with double back-off in one slot simultaneously in the multi-channel criteria to exploit the flexibility of OFDMA by extending the basic time-domain back-off procedure employed for standard ALOHA using a single channel. The idea of OFDMA-Aloha was originally proposed in [3] as a fast-retrial algorithm is explained in detail in Section I-A. Here we take N (finite) number of users and approximated new arrivals plus fast- retransmissions from frequency and time-domain retransmissions for the Poisson model. We derived the distribution of the access delay for a fixed number of channels *K*. However, the results do not allow a fair comparison between the single channel Aloha versus double back-of in OFDMA-Aloha for different values of *K*. The primary contributions of this paper are as follows. We provide a delay analysis of double back-off in OFDMA-Aloha in the saturated case which is helpful to study the limits of the protocol under various system settings. In terms of the number of channels *K*, number of users *N* and other parameters of the system, the *exact distribution of the packet access delay* is derived. Our results allow us to study the scalability of the double back-off in OFDMA-Aloha protocol with varying number of channels and compare it to the single channel Aloha under fixed system bandwidth and load conditions.

A. System Model and Assumptions

The model of double back-off in OFDMA-Aloha is shown in Fig. 1. In this model the total system bandwidth is divided equally into K channels. When packet get restricted to transmit there is collision arises in the system thus we take such a channel model so that transmission continued while packet get collision using double back-off in OFDMA-Aloha network and we assume that noise and other channel imperfection is negligible. Here a node with a packet goes to a channel out of K channels and transmit initially of the further next slot. When packet moves, if there is a collision occurs due to transmission error then packet will be retransmited in the next channel slot and if again collision occur it repeat the process of moving in the next slots up to the M (maximum) number of retrials is reached. If success is not achieved after this then it goes to the back-off mode for the fast retrial. This fast retrial procedure differentiates double back-off in OFDMA-Aloha from standard multi-channel Aloha. Let us consider the two systems single channel Aloha and the K channel OFDMA-Aloha with the double back-off taking same total channel bandwidth and the net arrival rate for a consistent and fair comparison. To represent Aloha we use subscript 1 while 2 for the double back-off in OFDMA-Aloha.

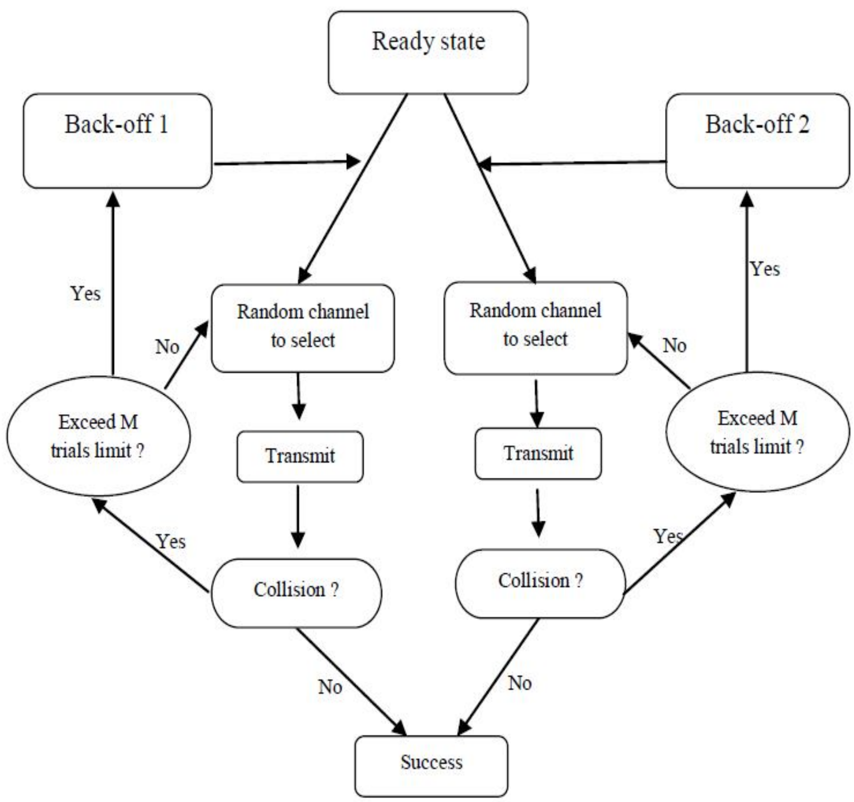

Fig. 1. Double back-off in OFDMA-Aloha MAC algorithm.

The system model for each case is represented in Fig. 2. Let us assume total bandwidth *B* (total channel rate *R* bits/second) and fixed packet size *L*. If there are *N* users, each with an infinite buffer. Packet transmission is only allowed at the slot boundary in both slotted MAC protocols. The time is divided corresponding to the packet transmission time over the total bandwidth into *mini-slots* of duration τ, i.e., $\tau = L/R$ seconds.

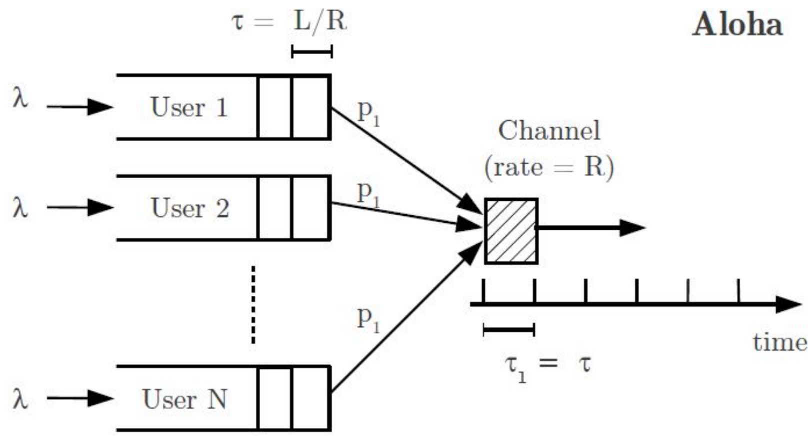

Fig. 2. 1. System model.

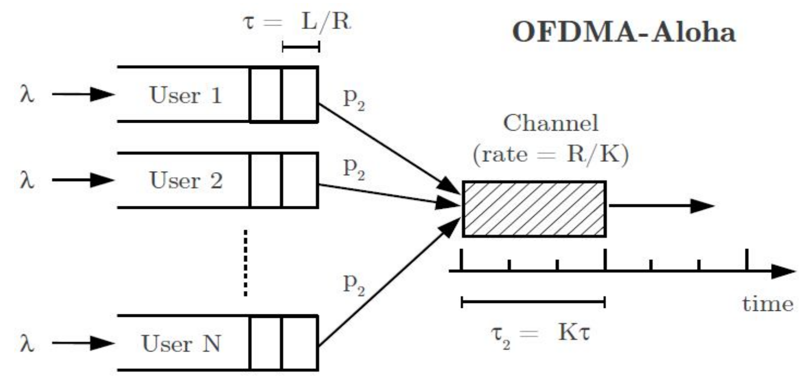

Fig. 2.2. System model.

The time dependent quantities are defined over the mini-slot τ. The slot duration for aloha is given by $\tau_1=\tau$ and for the double back-off in OFDMA-Aloha is given by $\tau_2=K\tau$ seconds. We use the model of delayed first transmission (DFT) for tractability from [5]. According to this model for all packets the same transmission probability is used whether it is new or old i.e., the transmission probability for all users is fixed for the all time slots. MAC protocols under the DFT model for "Double back-off in OFDMA-Aloha" is represented in following figure.

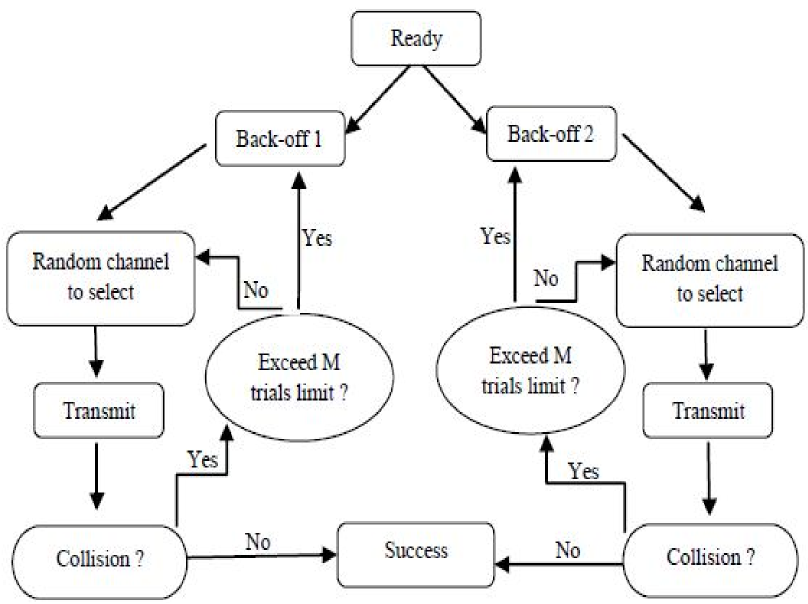

Fig. 3. Double back-off in OFDMA-Aloha flow chart under DFT model.

MAC protocols under the DFT model for "Aloha" is represented in following figure.

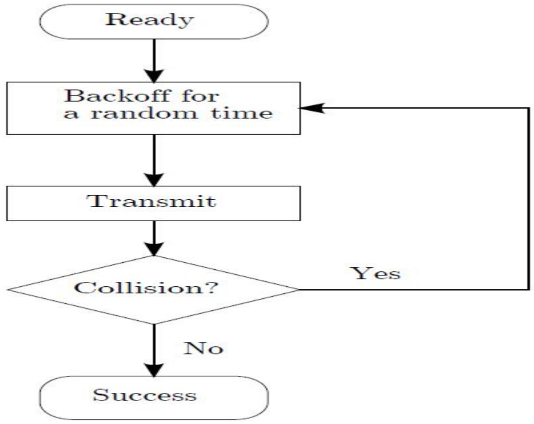

Fig. 4. Aloha MAC flow chart under the DFT model.

For a new arrival when we use this DFT model assumption, the node starts move instantly to the back-off mode. The node transmits or retransmits the head of line (HOL) packet with the probability p or defer to the next slot with the probability 1-p. Here we represent the transmission probability of Aloha by p_1 and the transmission probability for the Double Back-off in OFDMA-Aloha for first block is p_2 and for the second one is $1-p_2$. WE take the N number of users and K number of channels where N > K; otherwise the bandwidth becomes underutilized.

II. SATURATED CASE ANALYSIS

In this case we talk about every successful packet is replaced by new packet immediately, the quantity of interest is the output or the packet mean access delay d. Markov chain representing the state of the system in any slot and finding the state transition probability matrix is one of best approach to the analysis of such system. In single channel Aloha the system state in the saturated case is trivial and we need 2(M+1) dimensional Markov chain to represent the state of the system in our system model. If the fast-retry counter at user *i* is m_i, then the system state is given by either $\mathbf{n} = (n_1, n_2, \ldots, n_M, n_{bk1})$ or by $\mathbf{n} = (n'_1, n'_2, \ldots, n'_M, n'_{bk2})$ where n_i, n'_i denotes the number of users with fast retry counter m=i in the two blocks 1 and 2 of our system model respectively, n_{bk1} and n_{bk2} denotes the number of users present in block 1 and 2 respectively. We use the state flow graph technique of Markov process to derive the quantity of interest representing packet transmission in a typical, tagged user and transform analysis of the state flow graph for deriving the steady state distribution and moments of the process which is described in [6]. This technique has been used for the analysis of Tone Sense Multiple Access in [7] and for approximate queuing analysis of Aloha in [8] and CSMA/CD in [9]. We start by illustrating this technique for Aloha in order to facilitate the exposition of the more complicated OFDMA-Aloha system.

A. *Aloha Saturation Analysis*

The state transition diagram for the transmission of packet in Aloha is shown in Fig. 5. For the construction of state flow graph from the original state transition diagram of the process we multiply each branch between any two states by the Probability Generating Function (PGF) of the time (or number of steps) required for the transition. A packet is moves from ready state to the back-off state immediately, under the Delay First Transmission (DFT) assumption. If in every subsequent slot of the system the transmission probability of the user is p_1 and the defers transmission probability is $1 - p_1$, the probability of successful transmission by q_1, then the packet moves into the success state with probability $p_1 q_1$ and stays in the back-off state with probability $(1 - p_1) + p_1(1 - q_1)$. The PGF is just z times these probabilities because each of these two transitions require one time slot. If the user get success then the new user is ready to move in to the ready state and this process is repeats again. The total time spend in the state flow graph to move from the "Ready" state to the "Success" state of each packet is called the access delay and it is denoted by d_1. In the flow graph the transfer function from state S_r to state S_s is called the PGF of this delay and symbol for this is taken as $D_1(z)$. It can be obtained by using flow graph reduction methods or directly using Mason's rule, see [10]:

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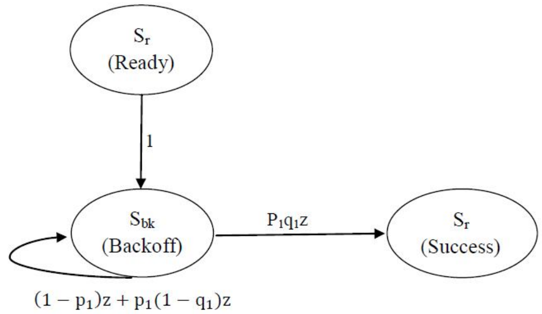

Fig. 5. State flow graph of packet transmission process in Aloha.

$$D_1(z) = \frac{p_1 q_1 z}{1-[(1-p_1)z+p_1(1-q_1)z]} = \frac{p_1 q_1 z}{1-(1-p_1 q_1)z} \quad (1)$$

where the average success probability q_1 of the tagged user in Aloha is given by:

$$q_1 = (1-p_1)^{N-1}$$

We can get the mean access delay d_1 (in mini-slots) by differentiating $D_1(z)$ at value of z=1.

$$d_1 = D_1'(1)$$

$$d_1 = \frac{1}{p_1 q_1} = \frac{1}{p_1(1-p_1)^{N-1}} \quad (2)$$

B. OFDMA-Aloha with double back-off Saturation Analysis

The state flow graph of our system model is shown in Fig. 6. We introduce here two back-off states ie, the channel consist of two sub channels. In this model each sub channel contain M additional states representing each stage of the fast retry mode. The packet moves in S_{bk} and in the S'_{bk} states from ready state with the transmission probabilities p_2 and $1-p_2$ respectively. We assume block-1 consist of S_{bk} state and block-2 consist of S'_{bk} state in our system model to simply our calculation. We take the probabilities of the successful transmissions as q_2 and q'_2 for block 1 and block 2 respectively. Now the user have two option to get success either it move through the path of block 1 or the path of block 2. If the user move through block 1 it defer by the probability $1-p_2$ and for the block 2 it defer by probability p_2. In block 1 when a collision occurs for the first time, the retry counter is incremented to $m = 1$, and the packet moves to state S_1 and if a second collision occurs in the following slot, the packet moves to state S_2, continuing this way until the maximum retry limit $m = M$ is reached in state S_M. The user "gives up" retrying and falls back into the back-off state S_{bk} and resets $m = 0$ when a collision occurs in state S_M. The same process works in block 2 of our system model. Note that in all the fast retry states: $S_1, S_2, ., ., ., . , S_M, S'_1, S'_2, ., ., ., . , S'_M$, the user transmits with probability 1, whereas in the back-off state S_{bk} and S'_{bk} he transmits with probabilities p_2 and $1-p_2$ respectively.

The probability generating function (PGF) for our system model to block 1 from state S_r to state S_s in the state flow graph using Mason's rule is given by as follows.

$$D_2^{(1)}(z) = \frac{p_2^2 q_2 z^2 (1-(1-q_2)^{M+1} z^{M+1})}{[1-(1-p_2)z-p_2(1-q_2)^{M+1} z^{M+1}]} \quad (3)$$

For block 2 the PGF is given by as follows.

$$D_2^{(2)}(z) = \frac{(1-p_2)^2 q_2' z^2 \left(1-(1-q_2')^{M+1} z^{M+1}\right)}{\left[\left(1-p_2 z-(1-p_2)(1-q_2')^{M+1} z^{M+1}\right)(1-(1-q_2')z)\right]} \quad (4)$$

Now the net expression for PGF in our system model is given as follows.

$$D_2(z) = D_2^{(1)}(z) + D_2^{(2)}(z) \quad (5)$$

If we substitute the value of $D_2^{(1)}(z)$, $D_2^{(2)}(z)$ in equation (5) we have following expression.

$$D_2(z) = \frac{p_2^2 q_2 z^2 (1-(1-q_2)^{M+1} z^{M+1})}{[1-(1-p_2)z-p_2(1-q_2)^{M+1} z^{M+1}(1-(1-q_2)z)]} + \frac{(1-p_2)^2 q_2' z^2 (1-(1-q_2')^{M+1} z^{M+1})}{[(1-p_2 z-(1-p_2)(1-q_2')^{M+1} z^{M-1})(1-(1-q_2')z)]} \quad (6)$$

The mean access delay d_2 in OFDMA-Aloha with double back-off is given by evaluating $D'_2(z)$ at the value of z =1. For finding the success probability q_2 we can follow an easier approach which will prove useful later. we apply the analysis transient Markov process described in [6, ch. 4]. Note that from the perspective of a newly arrived packet, the states: S_{bk}, S_1, S_2, ., ., ., S_M and S'_{bk}, S'_1,S'_2, ., ., ., S'_M are transient states and state S_s is a trapping, or an absorbing state. Therefore, the sums of the time spent in the back-off state and all fast retry states that is the total time spent in the transient process is the delay seen by the packet.

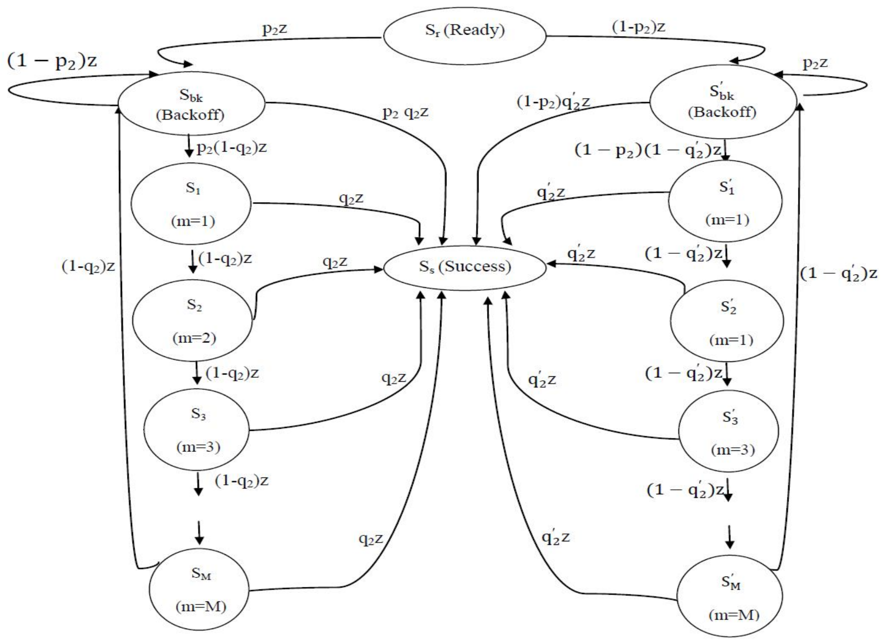

Fig. 6. State flow graph of packet transmission process in OFDMA-Aloha with double back-off.

Now we will find the average time spent in the transient back-off state, T_{bk} and T'_{bk}. First we evaluate the transfer function from the input state S_r to state S_{bk} to obtain the PGF of T_{bk}. We differentiate T_{bk} to get $E[T_{bk}]$. Alternatively, since we are interested in the first moment, we can find the path transmission gain from S_r to S_{bk} using a modified state flow graph with z = 1. Applying Mason's rule between state S_r and state S_{bk} in our modified flow graph, we get the average time spent in the back-off state:

$$T_{bk} = \frac{1}{p_2 - p_2\ (1-q_2)^{M+1}} = \frac{1}{\Delta}$$

Where $\Delta = p_2 - p_2\ (1-q_2)^{M+1}$. Similarly we find average time spent in the transient back-off state, T'_{bk} which is given as follows.

$$T'_{bk} = \frac{1}{(1-p_2) - (1-p_2)(1-q'_2)^{M+1}} = \frac{1}{\Delta'}$$

Where $\Delta' = (1-p_2) - (1-p_2)(1-q'_2)^{M+1}$. Similarly we find the average time spend in all the fast retry states as follows.

$$T_1 = \frac{{p_2}^2(1-q_2)}{\Lambda}$$

$$T_2 = \frac{{p_2}^2(1-q_2)^2}{\Lambda}$$

....

$$T_M - \frac{{p_2}^2(1-q_2)^M}{\Delta}$$

And

$$T_1' = \frac{(1-p_2)^2(1-q_2')}{\Delta'}$$

$$T_2' = \frac{(1-p_2)^2(1-q_2')^2}{\Delta'}$$

……….

$$T_M' = \frac{(1-p_2)^2(1-q_2')^M}{\Delta'}$$

The mean access delay is the total time spent in the transient process (in mini-slots):

$d_2 = (T_{bk} + T_1 + T_2 + \ldots + T_M + T'_{bk} + T'_1 + T'_2 + \ldots + T'_M) \times K$

$$= \left(\frac{1}{\Delta} + \sum_{m=1}^{M} \frac{p_2^2(1-q_2)^m}{\Delta} + \frac{1}{\Delta'} + \sum_{m=1}^{M} \frac{(1-p_2)^2(1-q'_2)^m}{\Delta'}\right) \times K$$

$$= \left[\frac{q_2 - p_2^2 q_2 + p_2^2(1-(1-q_2)^{M+1})}{p_2 q_2 (1-(q_2)^{M+1})} + \frac{q'_2 - (1-p_2)^2 q'_2 + (1-p_2)^2(1-(1-q'_2)^{M+1})}{q'_2(1-p_2)(1-(1-q'_2)^{M+1})}\right] \times K \quad (7)$$

Where the multiplier K signifies that the slot size in OFDMA-Aloha is K mini-slots. In this paper we discuss the case when we have $q_2 = q'_2$ then mean access delay is given by.

$$d_2 = \frac{p_2(1-p_2)(1-(1-q_2)^{M+1}) + q_2(1-p_2+p_2^2)}{p_2(1-p_2)q_2(1-(1-q_2)^{M+1})} \times K \quad (8)$$

Next we find the probability of success q_2 for the tagged user in our system model. The average transmission probability of any user in any slot and the set of all states by $S = \{S_{bk}, S_1, S_2, ., ., ., S_M, S'_{bk}, S'_1, S'_2, ., ., ., S'_M\}$ is denoted by p_t and is given by.

$$p_t = \sum_{i \in S} \Pr[\text{user transmits} \mid \text{state } i]\Pr[\text{state } i]$$

$$= p_2 \times p_{bk} + 1 \times p_f + (1-p_2) \times p'_{bk} + 1 \times p'_f \quad (9)$$

Where p_{bk} and p_f are the probabilities of the tagged user being in the back-off state (S_{bk}) and the fast retry mode (states $S_1, S_2, \ldots, S_M$) respectively, p'_{bk} and p'_f are the probabilities of the tagged user being in the back-off state (S'_{bk}) and the fast retry mode (states $S'_1, S'_2, \ldots, S'_M$) respectively. To find the expression for p_{bk}, p_f, p'_{bk} and p'_f we use the transient process analysis, p_{bk} and p'_{bk} are the proportion of the time spent in the back-off modes S_{bk} and S'_{bk} respectively and are given by as follows.

$$p_{bk} = \frac{E\{\text{time spent in the back-off state } S_{bk}\}}{E\{\text{total time spent in the transient process}\}}$$

$$= \frac{T_{bk}}{d_2}$$

$$= \frac{q_2(1-p_2)}{p_2(1-p_2)[1-(1-q_2)^{M+1}] + q_2(1-p_2+p_2^2)} \quad (10)$$

$$p'_{bk} = \frac{E\{\text{time spent in the back-off state } S'_{bk}\}}{E\{\text{total time spent in the transient process}\}}$$

$$= \frac{T'_{bk}}{d_2}$$

$$= \frac{p_2 q_2}{p_2(1-p_2)[1-(1-q_2)^{M+1}] + q_2(1-p_2+p_2^2)} \quad (11)$$

Similarly p_f and p'_f are the proportion of time spent in the fast retry modes and are given by:

$$p_f = \frac{E\{\text{time spent in all fast retry states}\}}{E\{\text{total time spent in the transient process}\}}$$

$$= \frac{\sum_{m=1}^{M} T_m}{d_2}$$

$$= \frac{p_2^2(1-p_2)(1-q_2)(1-(1-q_2)^M)}{p_2(1-p_2)[1-(1-q_2)^{M+1}]+q_2(1-p_2+p_2^2)} \quad (12)$$

$$p'_f = \frac{\text{E[time spent in all fast retry states]}}{\text{E[total time spent in the transient process]}}$$

$$= \frac{\sum_{m=1}^{M} T'_M}{d_2}$$

$$= \frac{p_2(1-p_2)^2(1-q_2)(1-(1-q_2)^M)}{p_2(1-p_2)[1-(1-q_2)^{M+1}]+q_2(1-p_2+p_2^2)} \quad (13)$$

For transmission if the packet selects any channel c out of K. Since all remaining packets N-1 are taken as statistically identical and there is uniform channel selection with the probability 1/K. hence the probability of success of the packet for this channel is given by as follows:

$$q_2 = (1 - p_t \times \frac{1}{K})^{N-1} \quad (14)$$

If we substitute the value of p_{bk}, p'_{bk}, p_f and p'_f from the equations (10), (11), (12) and (13) to the equations (9) and (14), we get the non linear relation between probability of packet success and the probability of system parameters in our system model (OFDMA-Aloha with double back-off):

$$q_2 = [1 - \frac{1}{K} \times \frac{\{p_2(1-p_2)(q_2+(1-(1-q_2)^{M+1}))\}}{p_2(1-p_2)(1-(1-q_2)^{M+1})+q_2(1-p_2+p_2^2)}]^{N-1} \quad (15)$$

We can solve numerically q_2 to derive the mean access delay d_2 in (8).

In the analysis above, we assumed the DFT model in Fig. 3 and Fig. 4. For Aloha in the saturated case, this assumption does not set any significant difference, and hence we can use the result for d_1 in (2) without this assumption. If we allow unlimited number of fast retrials ($M = \infty$), the access delay in OFDMA-Aloha with double back-off is always larger than the access delay in Aloha regardless of the number of channels and it is given as follows:

$$d_2^{\infty} = \frac{p_2 + q_2}{p_2 q_2} + \frac{p_2}{(1 - p_2)}$$

where $d_2^{\infty} > d_1 \; \forall$ K > 1.

C. Numerical Results

We present the numerical results of single channel Aloha and double back-off in OFDMA-Aloha. We compare the numerical results of both models for the value of N=20, 25, 30,……,60, while for our system model (double back-off in OFDMA-Aloha) we consider K= 1, 2, 3, 4, 5 for both M=10 and M=15. In this context transmission probability is fixed and load line varies with the change in no of users. We assume the transmission probability (attempt rate) of Aloha to p_1 =1/N because we are working on a "symmetric" system of N homogeneous users. Mean access delay for the single channel Aloha shown in the fig. 7.

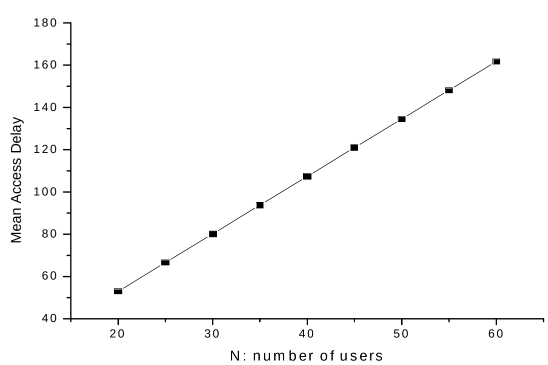

Fig. 7. Mean access delay for the single channel Aloha.

Since slot size is K times larger than that of Aloha therefore we fix the transmission probability for double back-off in OFDMA-Aloha for block 1 as $p_2 = K/N$, for block 2 is $1\text{-}p_2 = 1\text{-} K/N$, while q_1 and q_2 can take value in terms of K & N by the relations $q_1 = (1\text{-}p_1)^{(N-1)}$ and $q_2 = (1\text{-}p_2)^{(N-1)}$ respectively. In this paper we also consider the case $q_2 = q'_2$ and we discuss numerical results. Here in model double back-off in OFDMA-Aloha we see that for K = 1, 2, 3 and M=10 double back-off in OFDMA-Aloha gives better results as compared to single channel Aloha. which is shown in the following figure.

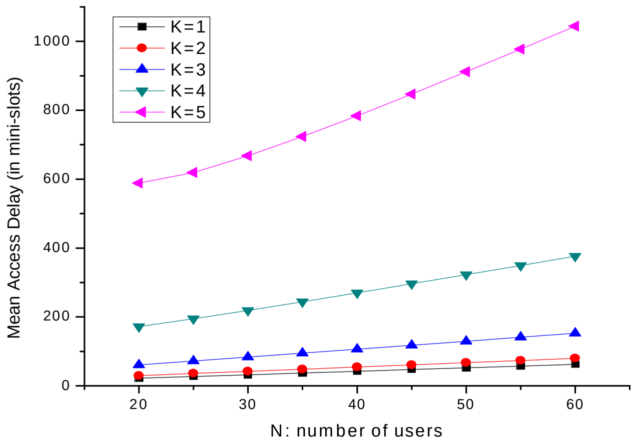

Fig. 8. Mean access delay in the saturated case for $M = 10$.

And for K = 1, 2, 3 and M=15 double back-off in OFDMA-Aloha also gives better results as compared to single channel Aloha. which is shown in the following figure.

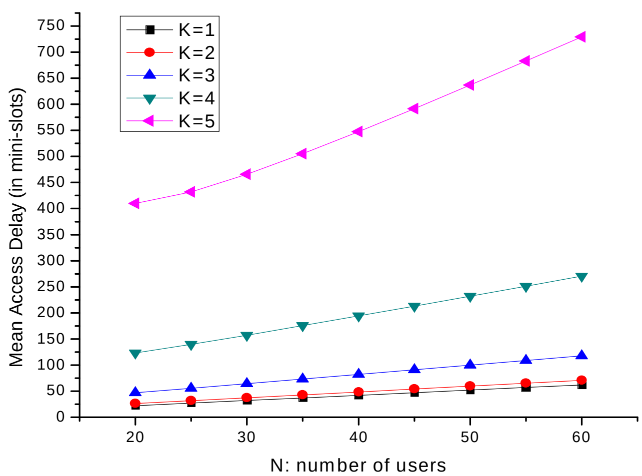

Fig. 9. Mean access delay in the saturated case for $M = 15$.

$p_2 = K/N$ gives similar performance to Aloha during the initial startup phase when all users are in the back-off state. To compute the numerical solution of d_2 in (8), we used the f-zero routine and the anonymous functions in MATLAB. In all cases of interest ($K < N$), the numerical results exist. In the saturated cased the mean access delay for $M = 10$, is shown in Fig. 8 and for M = 15 it is shown in the fig. 9. Our results show that the single channel Aloha performs better than OFDMA-Aloha with double back-off for K > 3 with M = 10 and for K > 4 with M =15, when all users are saturated. In the range of K = [1, 3] for M=10 and k = [1, 4] for M = 15 we see that mean access delay for thse system of OFDMA-Aloha with double back-off model is lower than that of the mean access delay for the single channel Aloha.

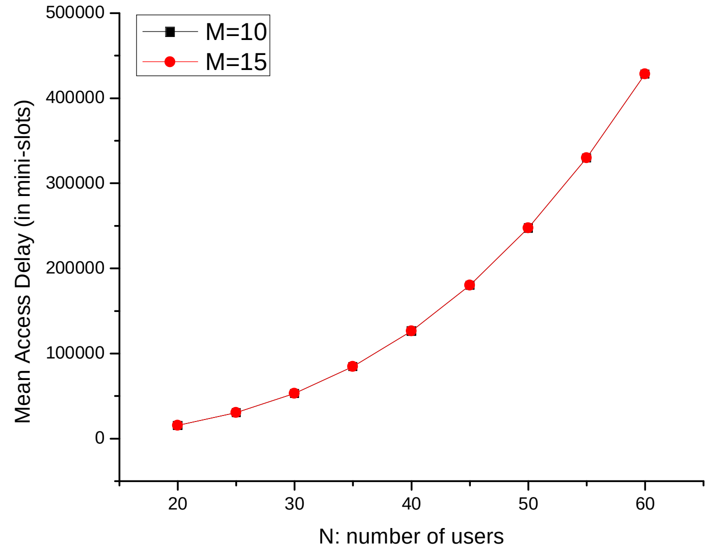

Fig. 10. Mean access delay in the saturated case for *K*= *N*.

However the basic idea of OFDMA-Aloha with double back-off is to reduce the retransmission time by reducing the collision probability. If we approach the value of K close towards the value of N we see that more mean access delay is achieved in the packet transmission. For example the value of d_2 is come closer to the value of the d_1 when we discuss the case for M = 15 with K= 3, which is very clearly shown in the fig. 7 and fig 9. If we take K = N for both the cases M = 10 and M = 15 we see that mean access delay for the system model is increases by higher rate, which is shown in the fig. 10. However, as the gap between *K* and *N* increases, the reduction in the collision rate decreases. This suggests that OFDMA-Aloha with double back-off might be helpful for lightly loaded network with low collision rates.

III. CONCLUSION

OFDMA-Aloha with double back-off is a new MAC protocol that promises to exploit the channel switching flexibility of OFDMA. This protocol try to reduce the packet retransmission time by reducing the packet collision rate over the frequency and time domains. By increasing the slot size or time scale and due to the lower channel rates it is capable to reduce the packet collision rate because it works in two blocks of a channel. Channelization does not bring substantial reduction in the collision rate when the network is already saturated. We see the single channel Aloha performs better than OFDMA-Aloha with double back-off especially when the number of channels and the number users come closer as we have seen in the numerical results. On other hand, OFDMA-Aloha with double back-off enjoys smaller packet delays, when the network is lightly loaded, but not for long as it saturates faster than the single channel Aloha. In the future we need for further study on the stability region of OFDMA-Aloha with double back-off and it may help develop practical adaptive algorithms for the future.

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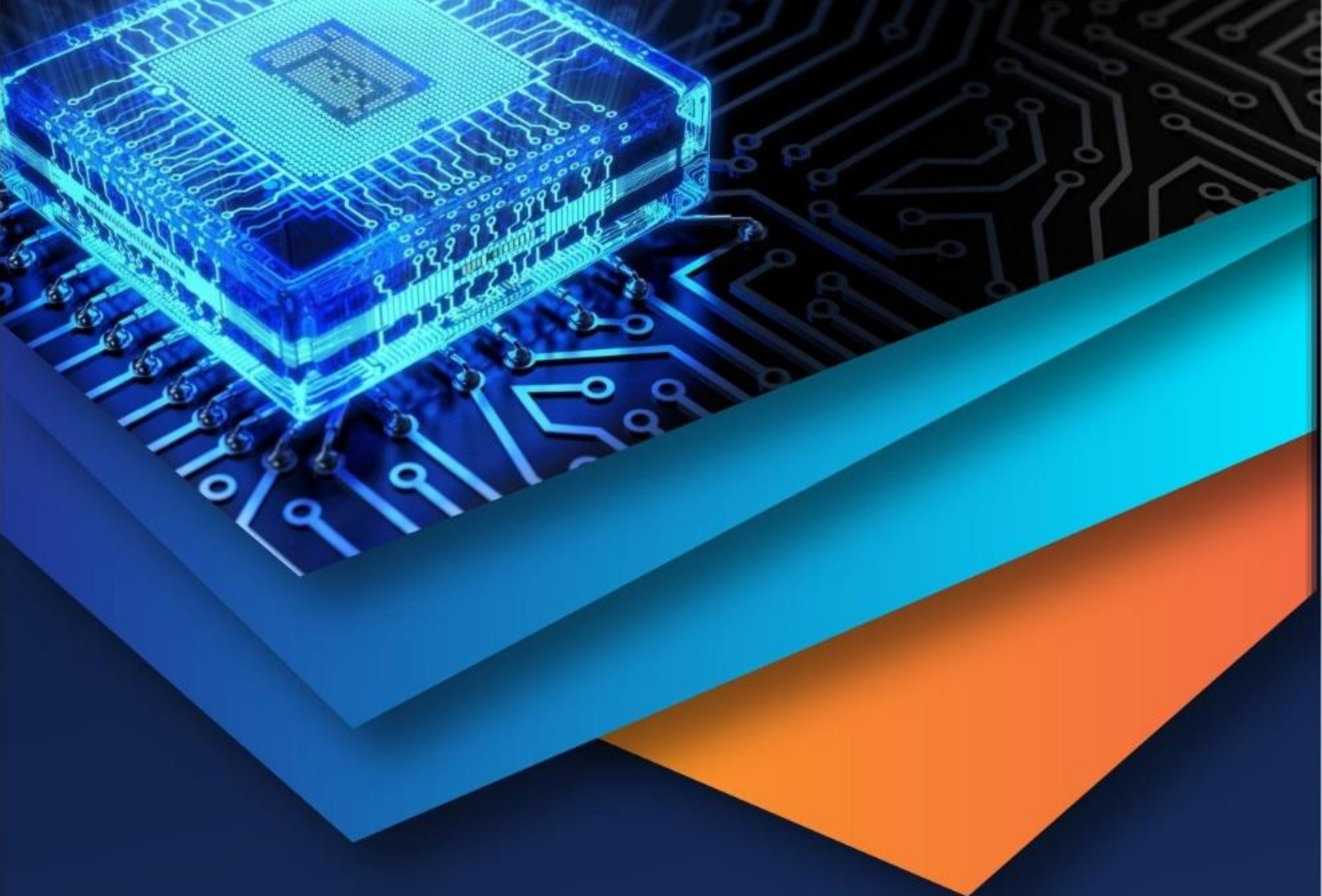

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