Hybrid Binary Exponential Back-Off Mechanism for Wireless Sensor Networks

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***Abstract*—Many mechanisms to improve the performance have been proposed in the IEEE 802.15.4 Wireless sensor networks area, due to its high influence in the modern day world. Most of them have improved the performance of the network compared to the standard CSMA/CA backoff method. But still there are improvements to almost every method proposed. In this paper, we have proposed a hybrid binary exponential backoff (HBEB), where we have used two mechanisms to effectively increase the performance, when there are moderate numbers of nodes. The performance analysis using markov chain analysis has been given in this paper along with simulation results for the proposed method.**

Keywords— HBEB, IEEE 802.15.4, back-off, markov chain, throughput.

I. INTRODUCTION

Since the standard CSMA/CA backoff mechanism was found to be insufficient in many cases, the scientists all over the world are trying to improve the existing methods. These modifications were done on the standard by following different approaches. The backoff exponent (BE) value was the main area of modification in following cases. In [2], the BE value was initialized to a new value called Efficient BE, which was calculated based on probability of completing the transmission successfully. In [4], the backoff delay is chosen from a different range, according to the number of failures and hence reduces the chance of nodes colliding again. In [6], a delayed backoff algorithm is proposed, where backoff period is assigned by the coordinator for the next transmission according to the demand in the current transmission. In [5], an interim BE value is chosen which is less than half of the actual BE value and the node performs CCA for the interim BE also. If successful, the node transmits, or else continues the original delay. In [7], the backoff delay duration is chosen according to Gaussian distribution and each of the nodes are given different mean and variance. In [8], adaptive method was used, where the initial backoff is changed dynamically according to the average collision rate.

The standard CCA procedures were modified in [1]. The information obtained by performing CCA1 and CCA2 is used and a third CCA is performed when CCA2 fails due to acknowledgement packet occupying the channel. In [3], the contention window size was determined adaptively according to the collision rate, and hence has a probabilistic approach of modifying CW. In [9], each node stores a value which gives indication about the local traffic rate, and these values can be modified according to the size of the network or the application of the network. So each node refers to this value for deciding the parameters for transmission.

In the method proposed in this paper, the node chooses the delay range between (2^{BE-1}, 2^{BE}-1) as suggested in [4], from its first failure onwards. But this method has a disadvantage that when the number of nodes are less, the output is lesser than the standard mechanism. When a collision occur in a scenario with less number of nodes, in most cases the nodes can retransmit without waiting for a long time. Therefore, to effectively improve the performance of the network in cases where there are less number of nodes, the nodes will perform CCA in between this backoff delay, in this procedure.

In this paper, section II contains a brief explanation of the standard CSMA/CA, section III contains the proposed HBEB algorithm and its analysis using markov chain. Section IV contains the analysis of performance of HBEB with the standard IEEE 802.15.4 CSMA/CA back-off algorithm. Section V concludes the paper.

II. THE STANDARD IEEE 802.15.4 CSMA/CA BACKOFF MECHANISM

The standard method uses slotted CSMA/CA and superframe structure for transmission. Superframe structure has beacons bounding it and active and inactive periods as shown in fig 1. In the Contention Free Period (CFP), all the nodes are allocated time slots by the PAN coordinator.

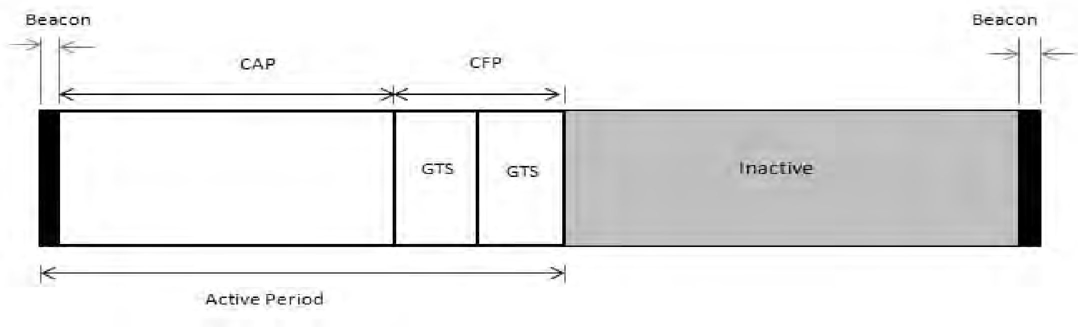

Fig 1: SuperFrame structure in IEEE 802.15.4

During the Contention Access Period (CAP), the nodes compete with each other for the channel access. So the CSMA/CA binary exponential backoff mechanism is used to allocate the channel. In this method, the node does not retransmit immediately in case of collision. The node will wait for an amount of time, which is calculated according to the predetermined BE value. There are two other variables Contention Window size (CW) and the number of backoff stages (NB) which have to be declared before the start of transmission. The value of NB is always initialized to 0. It is incremented every time a node fails to send. When it succeeds, it is reset to 0.

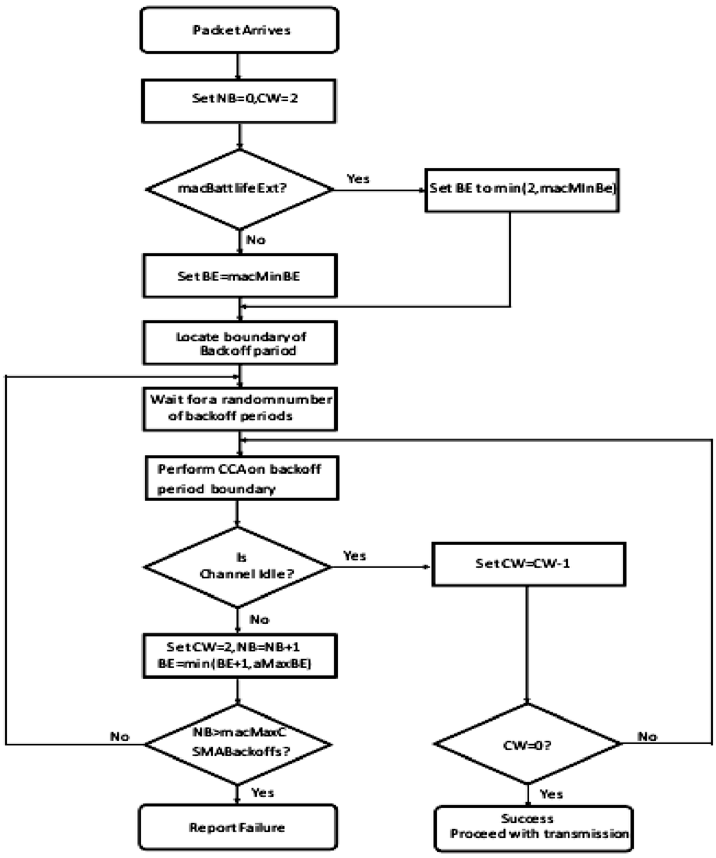

Fig 2: IEEE 802.15.4 Slotted CSMA/CA mechanism .

The packet is discarded if the node fails to send after the NB value reaches a predetermined value macMaxCSMABackoffs. BE maintains its value when it reaches its maximum macMaxBE, till it is reset. CW is the number of slots or periods which should be free of channel activity for the node to transmit. It is decremented till the channel is found to be empty for all the slots. It is reset in case of success or failure of the transmission. To make sure that the channel is free, Channel Clear Assessment (CCA) is performed, after waiting for a delay chosen randomly from (0, 2^{BE}-1) in cases of failure. The flowchart for the standard slotted CSMA/CA backoff mechanism is given in fig 2. After the backoff delay, CCA1 is performed, and if it succeeds, CCA2 is performed. Only after the success of CCA2 does the transmission start. If any of the two CCAs fails, the NB and BE values are incremented by one.

III. HBEB MECHANISM

In the standard algorithm, nodes choose their delay in the range of 0 to $2^{BE(i)}$-1. The nodes can choose their delay range according to the number of failures that node has encountered for sending a packet. The range is chosen by adjusting the selection range of backoff delay into ($2^{BE(i-1)}$,$2^{BE(i)}$-1) instead of (0,$2^{BE(i)}$-1). This method reduces the chances of collision because the range selected for the delay for each node will be different [4]. But when the number of nodes is small, the performance is lesser than the traditional BEB model. To rectify this, we can embed another mechanism. One of the solutions to improve the efficiency when the number of nodes are less is that each node will randomly wake up in between their delay at 10-40% of the original delay time. If the channel is free then, it will send the packet; otherwise it will wait for the remaining back-off time. This delay is also chosen randomly, so the probability of two or more nodes selecting both delays same is very less, hence less collision and also the performance is increased [5]. Therefore, by using this approach the zigbee network is expected to have less collision probability i.e higher throughput and performance especially when the numbers of nodes are less as the chances of channel being free during the interim back-off is more if the number of nodes is less. The proposed algorithm has been presented in the form of a flowchart in fig 3.

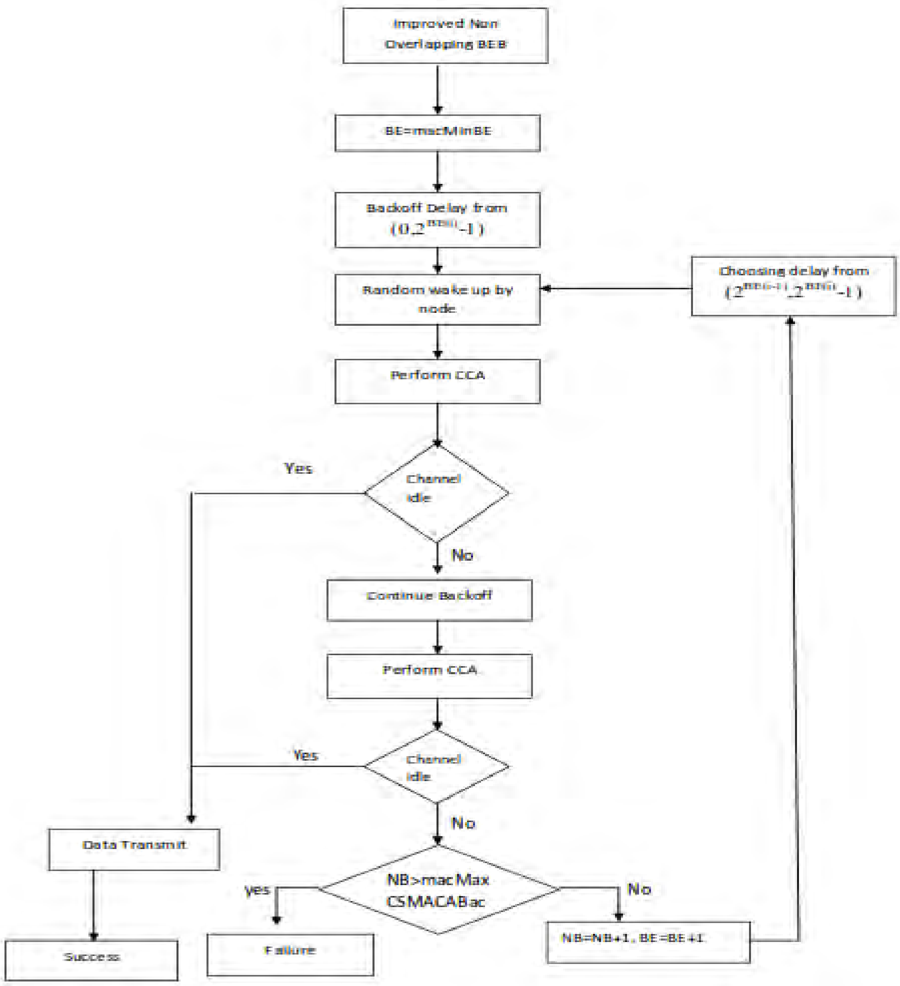

Fig 3: HBEB mechanism

A. MARKOV CHAIN ANALYSIS

The markov chain diagram for our algorithm is given in fig 4. In the diagram, each oval represent state in the delay counter. W_i is the 2^{BE} value where BE represent the backoff exponent in each level. It is the maximum time a node will wait in i^{th} stage. Each time a sending fails, the BE value is incremented. The n value represents the random period after which the node conducts CCA in between the delay counter. The node will continue its normal delay time, if both CCA's fail in the first case. The dotted lines represent the range in which the next delay is chosen from. It will be in the range of W_{m-1} to W_m-1.

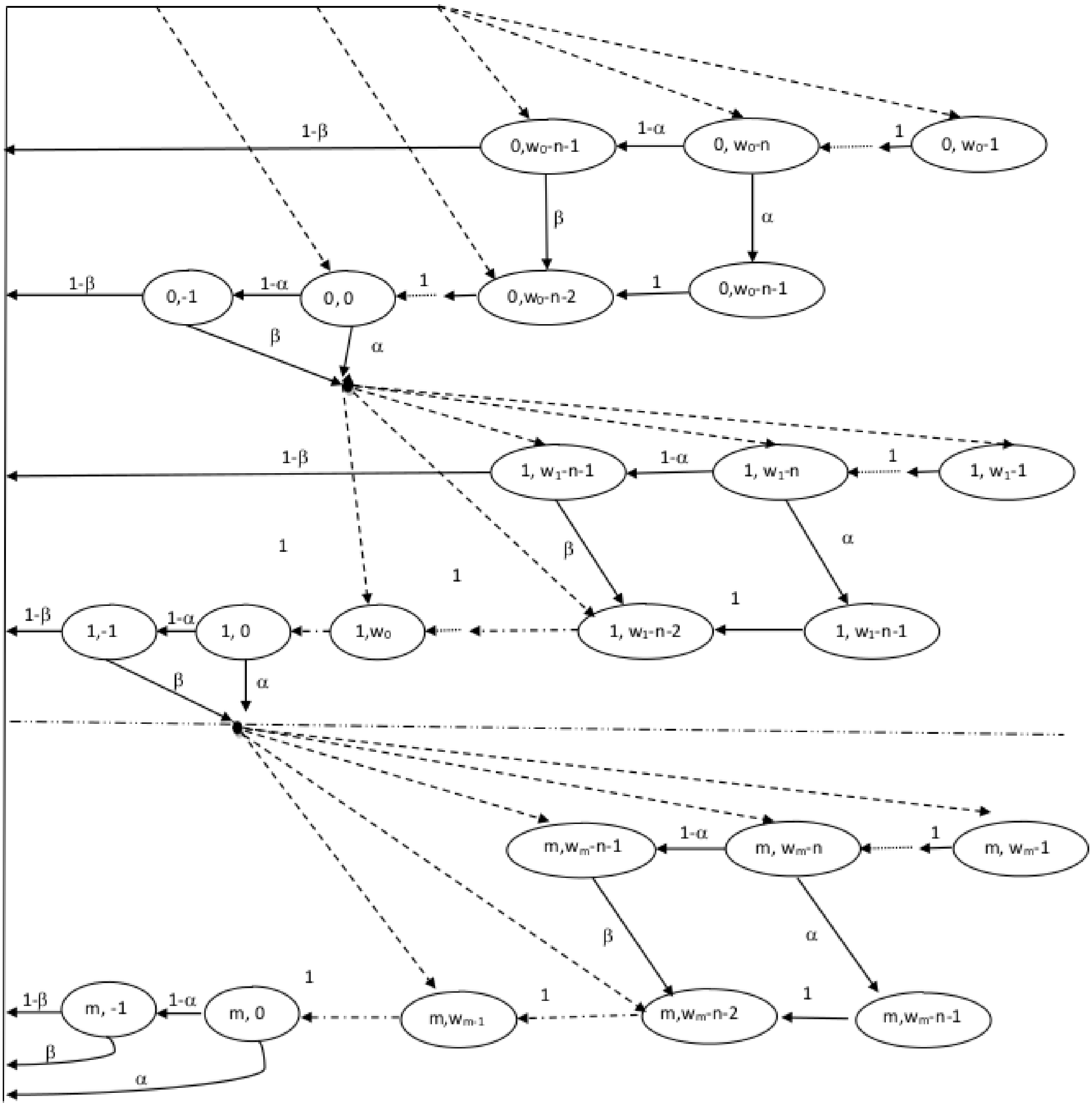

Fig 4: Markov chain for HBEB

From the markov chain diagrams, probabilities of transition from one stage to another can be calculated, and those equations can be used for evaluating the performance of the method. In the following equations, $P(b_{i,k}|b_{j,l})$ represents probability of transition from $b_{j,1}$ to $b_{i,k}$ and i, j vary from 0 to m and k varies from 0 to w_i. The transition probabilities are given below.

$P(b_{i,k}|b_{i,k+1})$= 1 where i ε (0.m) and k ε (W_m-n-1, W_m-1)

$P(b_{i,k}|b_{i,k+1})$= α+(1- α)β where i ε (0.m) and k ε (0, W_m-n-2)

$P(b_{i,-1}|b_{i,0})$= (1- α) where i ε (0.m)

$P(b_{i,k}|b_{i-1,0})$= $\alpha/W_{i-1}-W_i-1$ where i ε (0.m) and k ε (W_{i-1}, W_i-1)

$P(b_{i,k}|b_{i-1,-1})$= $\beta/W_{i-1}-W_i-1$ where i ε (0.m) and k ε (W_{i-1}, W_i-1)

$P(b_{0,k}|b_{i,-1})$= $(1-\beta)/W_0$ where i ε (0.m) and k ε (0, W_i-1)

$P(b_{0,k}|b_{m,0})$= α/W_0 where i ε (0.m) and k ε (W_{i-1}, W_i-1)

$P(b_{0,k}|b_{m,-1})$= $1/W_0$ where i ε (0.m) and k ε (0, W_i-1)

Here, α represents the probability of failure of CCA1, and hence 1-α represents the probability of success of CCA1. Similarly, β represents the probability of failure of CCA2 and 1-β, the probability of success of CCA2. Let p be the probability of finding the channel busy. So the equation for p will be $p = \alpha + (1-\alpha)\beta$.

From these equations, we can say,

$b_{i,-1} = (1-\alpha)\, b_{i,0}$

$b_{i,0} = b_{i-1,0}[\alpha(\alpha+(1-\alpha)\beta)] + (1-\alpha)\beta(\alpha+(1-\alpha)\beta)b_{i-1,0}$

ie. $b_{i,0} = b_{i-1,0}(\alpha+(1-\alpha)\beta)^2$

This can be generalized as:

$b_{i,0} = p^{2i}\, b_{0,0}$

$b_{i,k} = (\alpha+\beta-\alpha\beta)b_{i-1,0}$ $i \,\varepsilon\, (0,m)$, $k \,\varepsilon\, (W_{i-1}, W_i - 1)$

$b_{i,k}$ can be represented in terms of $b_{i,0}$ as,

$b_{i,k} = b_{i,0}$ where $i \,\varepsilon\, (0.m)$ and $k \,\varepsilon\, (0, W_i-1)$

$b_{i,k} = (W_i-k)/(W_i-W_{i-1})\, b_{i,0}$ where $i \,\varepsilon\, (0.m)$, $k \,\varepsilon\, (W_{i-1}+1, W_i - 1)$

Since sum of all the state probabilities is 1, we can equate the sum of the state equations of $b_{i,-1}$ and $b_{i,k}$ and get the equation of $b_{0,0}$ [4][10]:

$b_{0,0} = 1/[\,(1.5-\alpha)(1-p^{2(m+1)})/(1-p^2) + 0.75W_0(1-(2p^2)^{m+1})/(1-2p^2)]$

Let T be the probability that a given node attempts the first CCA, and it can be expressed as,

$T = {}_{i=0}\sum^{m} b_{i,0} = {}_{i=0}\sum^{m} p^{2i}\, b_{0,0}$ i.e.

$T = [(1-p^{2(m+1)})/(1-p^2)]/[\,(1.5-\alpha)(1-p^{2(m+1)})/(1-p^2) + 0.75W_0(1-(2p^2)^{m+1})/(1-2p^2)]$

B. TROUGHPUT AND DELAY CALCULATION

The throughput of the network can be given by the equation:

$S = (P_{transmit} * P_{success} * L_{payload})/E_{slot}$

Where $L_{payload}$ and E_{slot} are constants, and

$P_{transmit} = (1-(1-T)^n)\,(1-\alpha)(1-\beta)$

$P_{success} = [nT(1-T)^{(n-1)}\,(1-\alpha)(1-\beta)]/P_{transmit}$

These equations for throughput and delay have been adopted from [4]. $P_{transmit}$ denotes that the channel is idle at two CCA and $P_{success}$ is the probability that channel is accessed by one node. E[slot] is average slot length and L[payload] is the length of the payload and n is the number of nodes.

The delay for IEEE 802.15.4 is calculated as the time taken from the generation of the frame till it is transmitted. This includes the waiting time for the transmission and the transmission time. It can be represented as,

$D = E[X]\,\sigma + E[N_{CCAFAIL}]\, E[N_{CCA}]\, T_{CCA}$

Where E[X] is time consumed for backoff operations and for two CCA's $E[N_{CCAFAIL}]\, E[N_{CCA}]$, T_{CCA} is the duration of a CCA and σ is the backoff slot duration.

$E[X] = {}_{i=0}\sum^{m} k_i E[W_i]$

$E[W_i] = ¼[\,{}_{j=0}\sum^{I}\, [(W_j-1)/2]]$,

Where W_i is the average number of time slots that a successfully transmitted frame undergoes at the i^{th} backoff stage. k_i is the probability of successful transmission in the i^{th} stage.

$k_i = [p^{2i}(1-p^2)]/(1-p^{2(m+1)})$

$E[N_{CCAFAIL}] = {}_{i=0}\sum^{m} ik_i$

$E[N_{CCA}] = 3-\alpha-\alpha\beta+\beta$

IV. PERFORMANCE ANALYSIS

Here we compare the performance of the proposed HBEB algorithm with the standard BEB algorithm. Throughput and delay of both the algorithms have been calculated and the comparison charts are given in fig 5 and fig 6. The comparison has been made regardless of the constants present, as the difference will be the same, proportional to the variables.

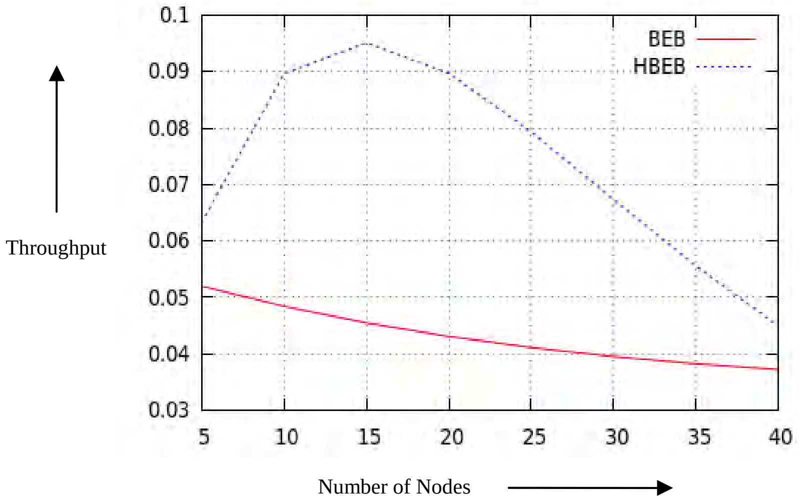

Fig 5: Throughput vs. Number of nodes

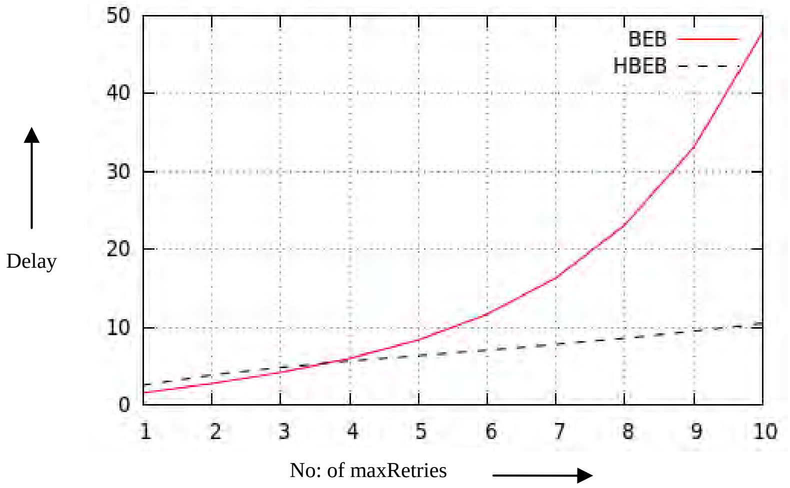

Fig 6: Delay vs. Max retries value

The analysis shows that the proposed algorithm gives better throughput when the number of nodes is not very high. The performance decreases as the number of nodes are increased and the standard BEB will be giving better throughput when the number of nodes are greater than 50. This limit can be adjusted by varying the maximum retry values. But the value very rarely or never goes above 10. The main reason for better performance when there are less number of nodes is that the nodes do not have to wait for long time if they encounter a collision.

The delay analysis showed that the rate of increase in the delay in HBEB mechanism is less compared to the standard BEB mechanism, as the macMaxCSMABackoff is increased.

V. Conclusion

In this paper we have proposed the HBEB mechanism which improves the performance of the network compared to the standard BEB when the number of nodes are not very large. The markov chain analysis of the mechanism has been given along with comparison of performances. This mechanism is an extension to the existing NO-BEB mechanism. For better performance in a network, the mechanisms can be used depending on the number of nodes which are present. Our future works involves improving our mechanism for larger of nodes in the network.

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