Backoff as Performance improvements Algorithms

A Comprehenssive Review

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Abstract—As a significant part of the Media Access Control protocol, the backoff algorithm purpose is to minimize number of collisions if not totally avoid any collision in Mobile Ad Hoc Networks, in the case of contention between nodes to access a channel. Researchers have proposed many algorithms for backoff to enhance the network performance and improve it.

This paper aims at exploring the main and most studied backoff algorithms and how do these algorithms lead to an enhancement of the MANETs performance. This paper also compares between the algorithms proposed in the literature and evaluates to what extent they have affected the performance and enhance it.

Keywords- *MANETs; Media Access Control; Backoff; Performance Measurement;Simulation.*

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I. INTRODUCTION

In an infrastructure-less environment of Mobile Ad Hoc Networks (MANET). In any transmission that takes place in the network the same case is valid. Whether the transmission is a unicast to a certain destination or it is a broadcast sending the packets through nodes in the transmission area, in a model called on-to-all. When the transmission fails and in order to avoid collision that affects the network performance, the Media Access Control (MAC) uses backoff algorithm to put the node to wait for a specific time before attempting to access the channel again [1][6].

As it is the case for all types of wireless networks, MANETs suffer the limited power resources. Therefore, it is vital to reduce Collisions that cause frequent failures in the network, and consume the power resources of the MANET. This highlights the importance of studying to what extent the protocol can utilize the backoff algorithm to enhance the performance of MANETs [2] [10].

The challenge remains even if backoff algorithms proof their ability to enhance the performance of the network. This is because the backoff algorithms are used to minimize the collisions but they cannot totally prevent or eliminate collisions [8]. One of the basic reasons behind this is the simple fact that backoff timers are not guaranteed to be unique among all contending nodes in the network. [9].

An efficient backoff algorithm can enhance the performance of the MANET in terms of minimizing collisions and power consumption. Moreover, the correct choice of backoff mechanism can improve both throughput and delay over the network [10].

This paper surveys the scenarios and methods that have been introduced in the literature, in terms of using backoff algorithms to enhance the performance of MANETs. In a step that states where the future work or concentration should focus.

II. MATERIAL AND METHODS

Medium Access control (MAC) is the main protocol that set the efficiency of WLANs and the effectiveness of sharing the limited network bandwidth of the channel [8]. The protocol capacity is indicated by the maximum value of the channel bandwidth fraction that is used in a successful transmission [10].

Due to the challenges that wireless and especially MANETs face, researchers have been looking for new algorithms that help in enhancing the performance of the network. This section reviews the methods, scenarios and algorithms for enhancing the network performance through using backoff algorithms.

This paper has surveyed 33 main articles, theses and reports including their references, covering the years from 2000 up to the end of 2016. In which the researchers focused on topics of Ad-Hoc networks, MAC protocol (IEEE 802.11), Fibonacci backoff, binary backoff, and many enhancements and modifications in known backoff algorithms to experiment the enhancements that these algorithms can make on the total throughput of the network.

In 2000, the researchers in [1] have defined the dynamic MAC protocol (IEEE 802.11); which was already designed to enhance the capacity of IEEE 802.11 network, by dynamically setting the backoff algorithm. In this study the researchers proposed a backoff algorithm that doesn't need any prior

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information about network or load condition. Instead, it works by observing the status of the channel and estimates the load configuration at the run-time. The researchers also focused on analyzing the tuning of the persistent IEEE 802.11 protocol instead of the standard protocol. [1] and [2] indicated that the optimal propagation delay value is the same as identifying the optimal window size of backoff in the standard protocol.

p_n = current optimal p approximation; (**)

Me_n = current M approximation;

Begin

step 1: $Idle\_p_{n+1}$ = (n+1)th estimate of the idle period;

step 2: $Coll_{n+1}$ = (n+1)th estimate of the collision cost;

step 3: $E[Idle\_p]_{n+1} = \alpha \cdot E[Idle\_p]_n + (1-\alpha) \cdot Idle\_p_{n+1}$

step 4: $$M_{comp} = \frac{\ln\left(\frac{E[Idle\_p]_{n+1}}{E[Idle\_p]_{n+1} + t_{slot}}\right)}{\ln(1-p_n)}$$

step 5: $Me_{n+1} = \alpha \cdot Me_n + (1-\alpha) \cdot M_{comp}$

step 6: $E[Coll]_{n+1} = \alpha \cdot E[Coll]_n + (1-\alpha) \cdot Coll_{n+1}$

step 7: $$p_{n+1} = 1 - \sqrt[Me_{(n+1)}]{\frac{E[Coll]_{n+1}}{E[Coll]_{n+1} + t_{slot}}}$$

End.

(**) The feasible range of p values has 1 as its upper bound (a station can use all the channel bandwidth when it is alone). The lower bound is set to the optimal p value for the maximum number of station allowed in the network (e.g 100 or 500) and the maximum message length.

Figure 1: the Backoff algorithm as studied in [9]

The procedure used, was found to be useful in any IEEE 802.11 network, if the congestion level is known it can help to select the appropriate contention window size. On the other hand, a Markovian model was developed in this research to study the performance of the dynamic IEEE 802.11. The results showed that the tuning is a very effective algorithm for the network and traffic configurations analyzed. To insure how the protocol work in case of possible errors during the estimation, the researchers investigated robustness of the protocol, and results showed that it can react to erroneous estimation processes [1][2].

After that in 2004, an adjustment of self-adaptive contention window algorithm was proposed by [3]. In this study, the results show that the proposed algorithm outperforms the standard algorithm in both cases of light and heavy contention cases. Also, the proposed algorithm doesn't require any prior or online measurements of the network.

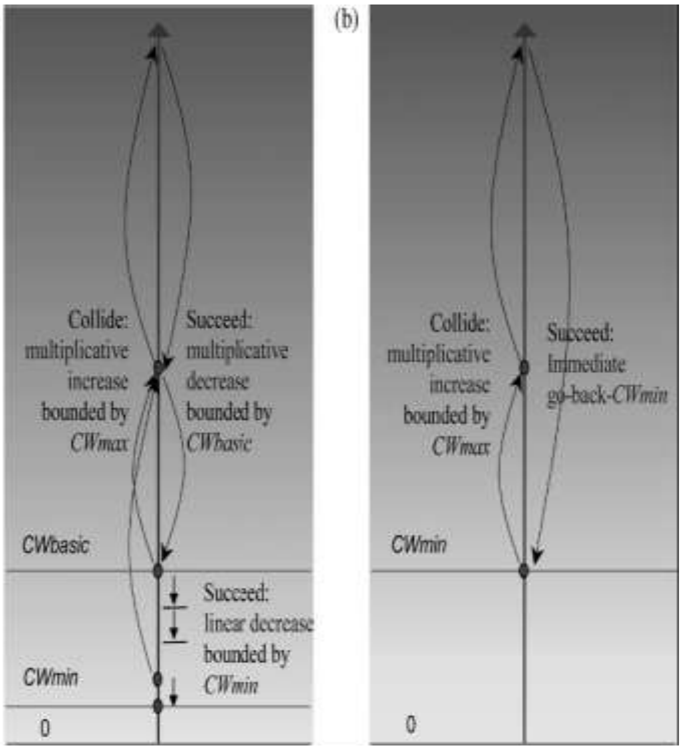
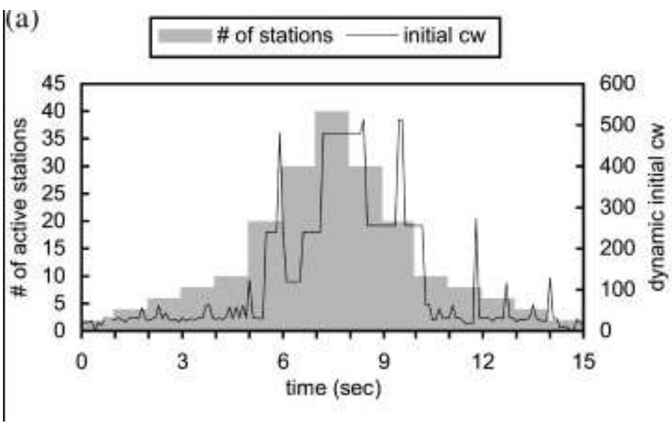


Figure 2: Comparison of the contention window evolution processes in the two algorithms. (a) Proposed algorithm. (b) Standard

The significance of this algorithm was in the ability of algorithm to automatically adjust the initial value of the contention window to the nearest optimal value according to the traffic to lead to the efficient use of the bandwidth. The researchers called it MIMLD (Multiplicative Increase Multiplicative/Linear Decrease) algorithm.

This algorithm (unlike the standard backoff algorithm that set the contention window initial always to CW $_{min}$,) takes into consideration the contention intensity. This algorithm is non-measurement based scheme in order to gain the ability of dynamically changing the initial contention window as the intensity requires [3][4].



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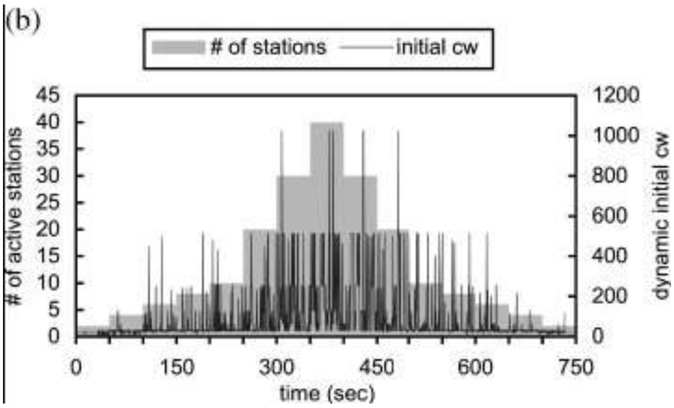

Figure 3: Dynamics of the sampled initial contention windows

The researchers in [3] focused on the performance improvement in both infrastructure and ad hoc mode of WLAN, the algorithm was found to be simple to implement because it doesn't require prior or online measurement as previously stated and minor adjustment is needed for the 802.11 firmware.

New performance analysis of the Exponential backoff (EB) algorithm, in 2005 the researchers of [5] have analyzed EB and got the saturation throughput and medium access delay for known number of nodes. The binary EB was taken into consideration in this study in which the backoff factor r=2. Moreover, the researchers made the analysis with the maximum retry limits. The results showed that some benefits were obtained, by limiting the number of transmission trials for a single packet; to give the other waiting packets the chance to transmit. The analysis of performance done in this study relies on having an equilibrium state not a dynamic one [5][6].

This is where [7][8] indicated that the changing the behavior of the backoff algorithm during transmission will affect the delay and throughput of the network. Which revealed that the BEB is not an optimal algorithm in MANETs.

Later in [2006], a new backoff algorithm was proposed by [9] to control the window size in large contention window, the results showed that the throughput especially in the large system sizes [9] [10].

In 2007, the researchers in [11] [12], have applied the EIED (Exponential Increase Exponential Decrease), for the ranging and changing BEB metrics, like the number of attempts/ period. The results of this study revealed that applying EIED algorithm proof a significant performance over BEB [11][13].

A modification for backoff algorithm was experimented in [14], in which an increment was logarithmically made not exponentially as BEB.

The modified logarithmic backoff algorithm
Step 0 : *set BO to the initial value*
Step 1 : *while BO ≠ 0 do*
For each time slot
If channel is idle then BO = BO -1
If channel is idle for more than IDFS then
Send
Else
*BO = log(BO)*BO*
Go to step 1
Stop

Figure 4: modified logarithmic backoff algorithm

Results of applying this algorithm showed higher throughput was achieved using this increment. As in the following figures 5 and 6.

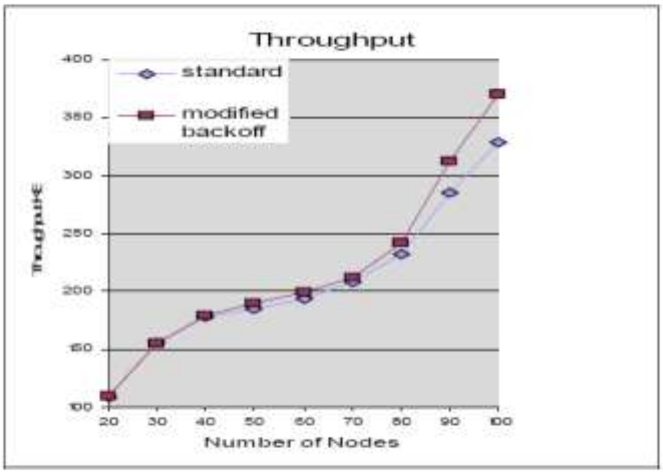

Figure 5: modified vs BEB

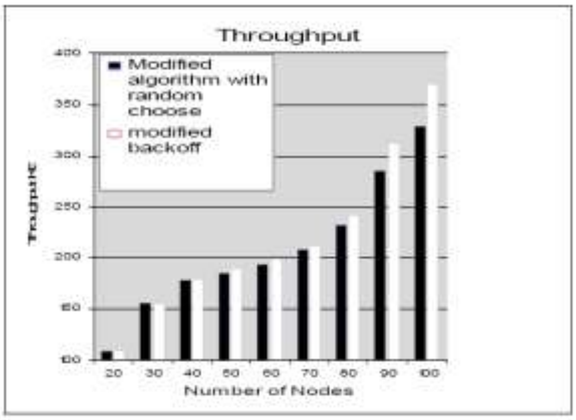

Figure 6: two versions of the modified

In order to be more specific regarding performance using different back off algorithms in different cases of podcasting in MANETs, the researchers of [16], have applied Fibonacci Increment back off algorithm (FIB), and the pessimistic Linear exponential back off (PLEB) under different cases of rebroadcasting. They have changes the number of nodes per area (density) in each experiment simulation, the results show that increasing the density with applying these algorithms of

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back off, the network performance enhanced and the delay became shorter.

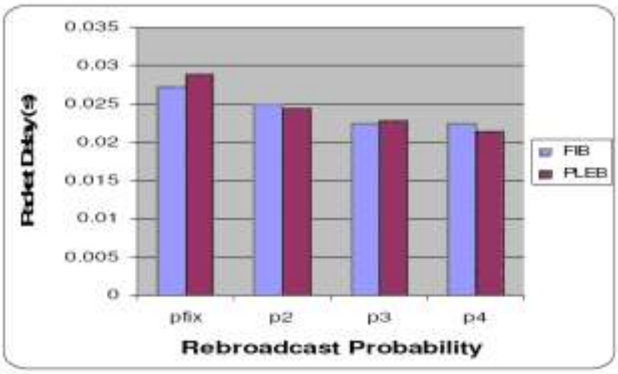

Figure 7: Rebroadcast probability vs. Network average End-End delay, in FIB and PLEB for 50 nodes

Some behaviors were used to increase the contention window size, and decrease the failure in [17], in the pessimistic linear-exponential backoff there are two behaviors for increment were introduced.

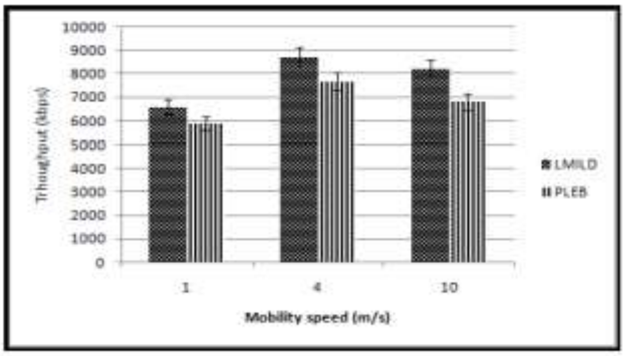

Figure 8: Network throughput for 10nodes, traffic rate of 100 packet/s

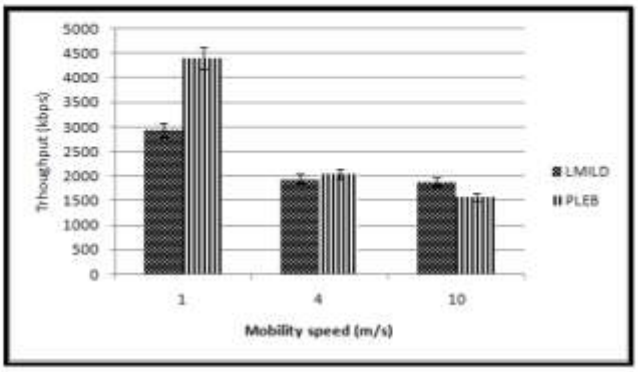

Figure 9: Network throughput for 100 nodes, traffic rate of 100 packet/s

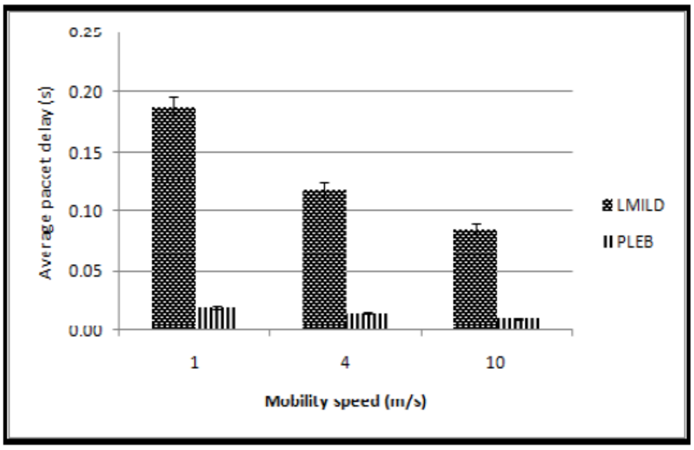

Figure 10: Average packet delay for LMILD and PLEB in a network of 100 nodes and traffic rate of 100 packets/

This algorithm has proven a significant improvement in the network throughput and reduces the packets delay, and led to better performance with low mobility speed.

In [18] the researchers tried to adopt the idea of Tay et al. (2004) in which he came up with the concept of “a geometrically increasing probability distribution for contention process”, they adopted the concept as an improvement in the backoff for the IEEE 802.15.3 contention process. Using analytical model they compared the IB and BEB in terms of the efficiency of channel. The comparison was done in both saturated and non-saturated conditions in the traffic.

Traffic load, number of nodes and mobility speed of a node, are factors that can affect the performance of MANETs, these factors where studied by [19], simulation was used to study the performance of a network under changing backoff algorithms. For transmission failure an increment behavior was performed, while decrement is performed in the case of a transmission success. These changing behaviors leads to change in the contention window size, which affect the network performance. Results showed that using large increments for CW improves MANETs throughput, but they also introduced large delay. On the other hand smaller increment improves the throughput, and decreases delays. The enhancement is clear in the case of large number of nodes and high mobility speed.

Based on the sequencing technique as an efficient technique for MAC. A new scheme was presented in [20], called the (VBA) Virtual backoff algorithm. The presented scheme aimed at minimizing the collisions number and simultaneously reducing the delays that occur during the backoff time. The new scheme used in this paper adopts the distributed mechanisms to access a channel over a wireless network.

The proposed algorithm measured the performance using various conditions. The improvement was in the bandwidth utilization, by increasing the throughput to 75% as well as decreasing the collisions to 65%, comparing to legacy

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protocols. Also, limiting the transmissions number led to energy saving.

Contention and collision, redundancy of packets are the main reasons for the broadcast storm problem. For what researchers in [21] have proposed probabilistic scheme to solve this problem. The factors studied were the density, mobility of network and their effect on the probabilistic schemes in different three fixed threshold levels (2p, 3p, and 4p) with pessimistic linear exponential backoff algorithm and the results of simulation were compared to the standard MAC. Results revealed that in the case of dense network and normal load the delay is high as well as the routing packets, and the pessimistic algorithm outperforms the standard MAC.

An experiment was conducted in [22] to enhance the backoff algorithm to increase the throughput and decrease collisions and enhance the overall performance of networks (MANETs), a modification was proposed for the backoff algorithm in such that the size of contention window is chosen either linearly or Fibonacci.

```
Step 0: set BO to the initial value
Step 1:  while BO ≠ 0 do
        For each time slot
                If channel is idle then BO=BO-1
        If channel is idle for more than IDFS then
                Send
        Else
                BOi+1= fib (i)
                Go to step 1
        Stop
```

Figure 11: The enhanced fibonacci backoff algorithm

In the case of high number of nodes the results showed that this experiment achieved high performance and decreased delay comparing to the binary backoff algorithm.

In [23] an increment behavior was introduced to decrease and avoid failure of transmissions. Since the binary exponential backoff may cause large contention windows gaps which can lead to transmissions failure. Results of applying such incremental behavior, made the contention windows shift to its right place according to the previous transmissions, which outperformed the BEB algorithm, the Smart adaptive backoff, and Pessimistic linear algorithm to 7.1%, 16.5% and 19% respectively in term of data delivery ratio.

```
1   Set BO to initial value
2   While Bo ≠0 do
3   For each time slot
4       If channel is idle then BO=BO -1
5           Wait for a period of DIFS then Send
6       If (Send-Failure) then
7           Save the CW_f = CW_current / 2
8           CW_new = CW_current * 5
9           Y = CW - CW_f
10          Backoff-Timer = Random x % Y + CW_f;    1 ≤ x ≤ CW - 1
11    Else
12        Reset CW, CW_f to minimum, minimum / 2, respectively
13  Go to line number 1
14  Stop
```

Figure 12: The Intelligent Paging Backoff Algorithm

On the other hand the implementation of a novel backoff algorithm outperformed the original IEEE distributed coordination function, since it uses binominal distribution instead of a uniform one. This showed an enhancement in the performance of a backoff algorithm [24].

Some network problems such as denial of service can be caused due to the misbehavior of backoff time, when manipulated by the node. In [25] a new measure "order gain metric" was introduced to describe and compare the benefits of misbehaving nodes to the logical and legal ones. Backoff misbehavior was defined in two types: continuous and intermittent, the first one is not stoppable unless disabled by countermeasures, while the second comes in interrupted form. The throughput of the misbehaving nodes was almost proportional compared to the legitimate ones [26] [27].

An evaluation of the binary exponential backoff algorithm (BEB) was performed in [27], this algorithm is considered as special case when r=2, so researchers in [15] used MATLAB to evaluate the performance when r varies in these values { 1.1,1.2,1.3,1.4,1.5,1.6,1.7,1.8,1.9,2.0}, the evaluation was studies in terms of delays for a given node numbers, and congestion avoidance.

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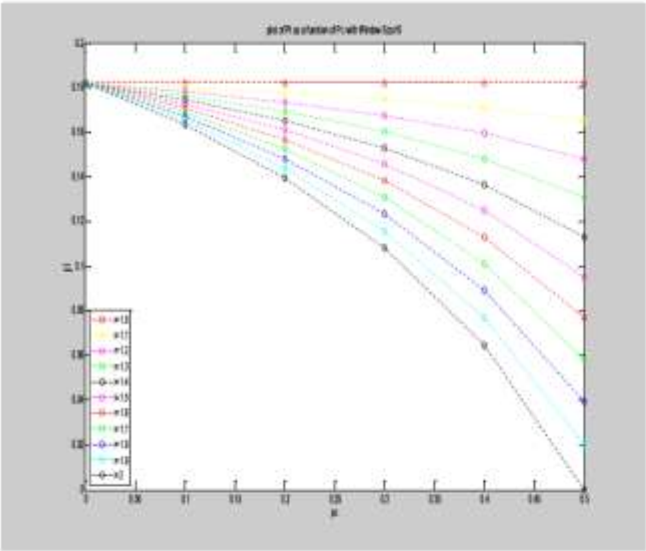

Figure 13: Relation between Pc and Pt with Window Size 10

The study showed that the throughput depends on the parameters, and the binary exponential backoff method limits the medium delay, by bounding and minimizing the tries number of transmission for the packets waiting.

In 2015, [28] used a reverse of the BEB algorithm to build a specific receiver- initiated protocol, to which pooling approaches where applied. In this study the pooling of the nodes is studies in terms of the pooling order, pooling rate. The researchers assumed that pooling has an effect on the performance of the backoff algorithm, since a slow polling rate can cause low throughput and increase delays. So controlling the polling will lead to control traffic and bound the collisions.

Using the BEB in this research is significant since it helps to keep the polling rate self-regulated, taking into consideration the traffic conditions at the polled nodes also it speeds the polling rounds. The results of performance analysis showed that the MAC initiated receiver protocol helps to ensure high control overhead, and the polling disciplines overcome the IEEE 802.11 when the nodes are scattered, and homogeneous traffic.

In [29], a multichannel backoff algorithm (MCB) performance is analyzed, with specific parameters to provide a good put. The MCB provides non-zero performance regardless the network size [29][30].

A comparable study for performance analysis of existing backoff algorithm was performed in [31], the analysis shows that controlling the contention window growth can enhance the short term fairness.

Another algorithm was proposed and used to enhance the performance of the backofff in IEEE 802.11 MANETS in [32]. The algorithm is an adaptive backoff for contention windows size, in which the algorithm estimates the number of active stations and calculates the optimal CW accordingly.

Step 1: Set CW_{min}, and set the threshold value for the collision probability Th_{Coll}.
Step 2: Calculate P_{Coll} using (5).
Step 3: Compare P_{Coll} with Th_{Coll}.
while ($P_{Coll} \geq Th_{Coll}$)
Estimate the number of active stations using (11).
Calculate CW_{min} obtained by (10) using n_{est}.
Update the P_{Coll} value using (5).
End
Step 4: Estimate the number of active stations using

Figure 14: Estimation of the number of active stations algorithm.

while (contention)
A station observes the channel for backoff period.
Calculate P_{Coll} using (5).
Estimate n_{est}, following the procedure in Algorithm 1.
Calculate CW_* using (10).
Choose a random backoff value from the range $[0, CW_* - 1]$.
Decrement backoff timer by one when the channel is idle as DCF protocol.
Transmit a packet when the backoff

Figure 15: Adaptive backoff algorithm of contention window, algorithm

The channel state probabilities by observing is measured for each station, the results showed that the adaptive backoff led to a better performance comparing to the fixed one, and decreased the collision probability with a high throughput and high fairness.

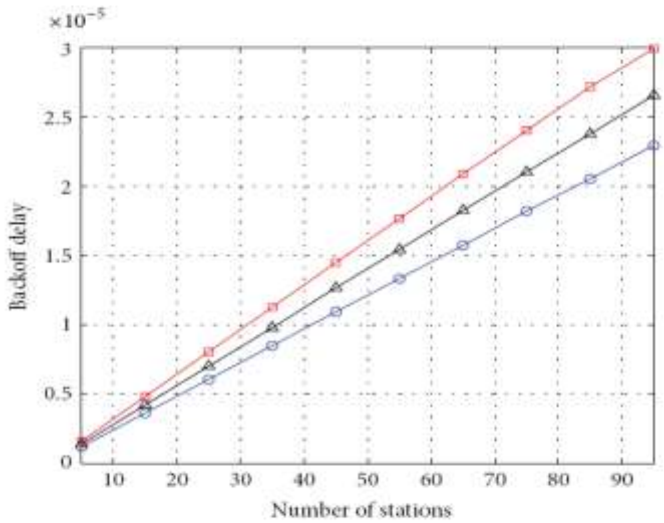

Figure 16: Backoff time versus the number of stations

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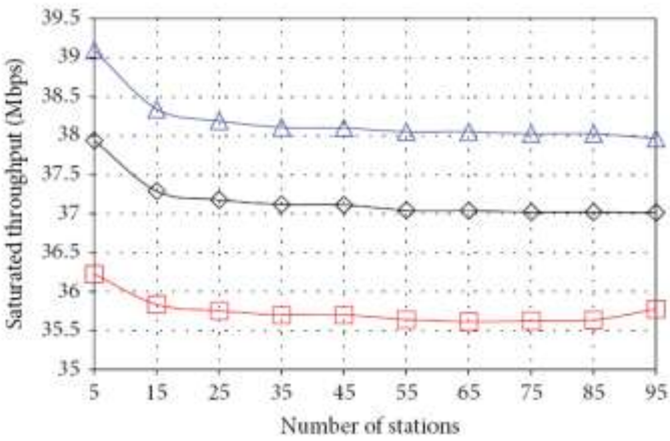

Figure 17: Throughput versus the number of stations

In [33] the history based backoff algorithm was modified to measure the enhancement of performance, by modifying the increment/ decrement behavior of the CW. This algorithm named history based increment backoff has proved its efficiency by outperforming the history based probabilistic one, in terms of throughput and delays, in different scenarios of nodes number and traffic density.

```
Initially, Contention Window CW is set to CWmin, C=0, S=0
RetransmissionCount = 0.
While there is Data frame to send do
        If Transmission is Collision then
                C =C + 1
                RetransmissionCount =RetransmissionCount + 1
        Else
                S =S + 1
        End if
        If Pn is the probability estimation of Tn
                Transmission then
                For i = 1, 2, 3, 4, …, (n - 1) do
                        β=∑ [±10^(i-n)*5^(n-i+1) modulo2*10└ (n-i-1)/2┘ ]
                End for
                If successful Transmission then
                        P= C/(C+S)
                        α= -1 + (P × 2)
                        CWnew = MAX [CWmin + 1, CWPrev × 2^α]
                Else
                        P= C/(C+S) +abs (β)
                        If P>1 then
                                P=1
                End if
                α= -1 + (P × 2)
                CWnew = MIN [CWmax - 1, CWPrev × 2^α]
        End if
        If RetransmissionCount>RetransmissionLimit then
                CWnew = CWPrev
                Set receiver Node Not Reachable
        End if
End while
```

Figure 18: proposed algorithm in Ref 33

The experiment was conducted in terms of different packet rates and number of nodes. The increment step caused an increase in the backoff, but decreases the contention between the nodes thus they will meet faster, which consequently results in high throughput and decreasing the delay time. Thus, enhancing the performance of the network.

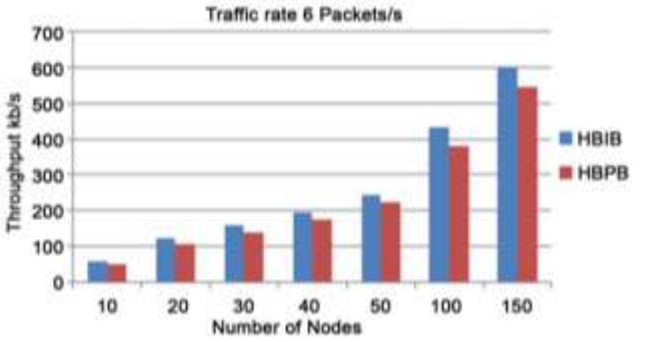

Figure 19: Simulation result of network throughput versus number of nodes and traffic rate 6

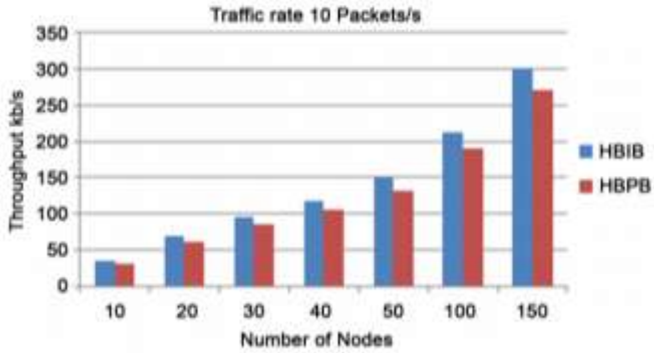

Figure 20: Simulation result of network throughput versus number of nodes and traffic rate 10

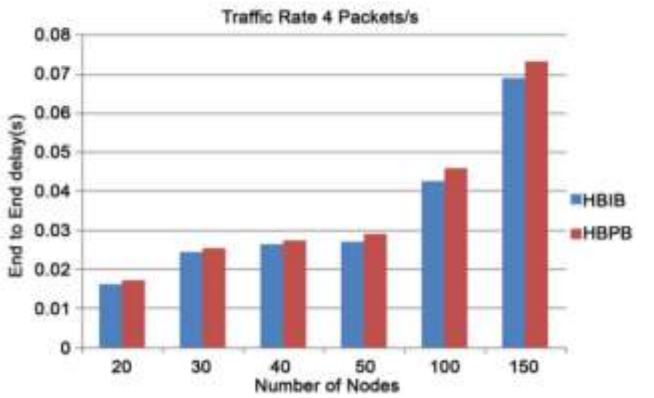

Figure 21: Simulation result of end-to-end delay versus number of nodes and a traffic rate of 4

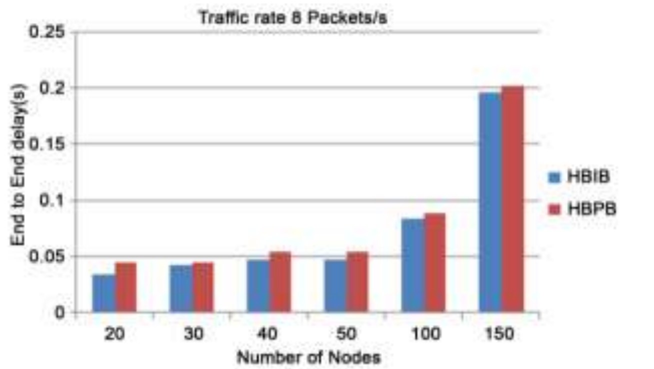

Figure 2214: Simulation result of end-to-end delay versus number of nodes and a traffic rate of 8

III. Conclusion

Most of the studies surveyed in this paper, have searched the performance of backoff algorithm and how to enhance it, through these following parameters: Simulation time, packet size, Area of network, number of nodes, speed, traffic load, transmit energy, contention window (Min, Max) size, warm up time.

Most of the experiments showed an enhancement in performance, using backoff algorithms, in terms of reducing collisions and resulting in high throughput. Considering the network conditions and settings of the studies parameters. This implies that backoff algorithm either the traditional one or the modified in the experiments is a significant factor that should be studied well to enhance the performance of the wireless network, increasing the efficiency and decreasing the collisions and delays.

IV. Recommendations

More research should be conducted in the field of back off algorithms and more parameters should be taken into considerations.

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