IEEE/IFIP Network Operations and Management Symposium

23-27 April 2018 // Taipei, Taiwan

Cognitive Management in a Cyber World

Welcome | Committee | Program | Venue

Welcome

WELCOME MESSAGE BY GENERAL CHAIRS

Welcome to the 2018 IEEE/IFIP Network Operations and Management Symposium (NOMS 2018) 23-27 April 2018 in Taipei, Taiwan. NOMS has been held in every even-numbered year since 1988. This is the 30th anniversary of NOMS. We warmly welcome you all to participate and celebrate the long and successful tradition of NOMS in Taipei.

We are proud to continue our tradition with a number of exciting programs at NOMS 2018. We are sure you will enjoy our exciting program including keynotes, panels, technical sessions, demo sessions, dissertation session, mini-conference sessions, poster sessions, tutorials, and workshops. These events provide rich opportunities for participants to learn, share, exchange, and identify the current and future directions and developments of network operations and management key issues.

It’s been an exciting in recent years for the NOMS community. A lot of new and challenging research and developments have been on-going worldwide, including 5G networks, software defined infrastructures, open source networking, IoT, etc. We have set the main theme to “Cognitive Management in a Cyber World” for this year to emphasize the strong demands for proactive and intelligent management of the more and more complex network and service environments.

It has been an honor serving as the NOMS 2018 General Chairs. We would like to thank our volunteers, sponsors and partners for their dedication and support. We are very grateful to all of you for your continual support. To everyone who has traveled to Taiwan, welcome to Taipei, a capital city renowned for its cultural and entertainment attractions. We encourage you all to enjoy and explore this fine city.

Sincerely,

Yuan-Kuang Tu, Honorary General Chair
James Won-Ki Hong, General Co-Chair
Yu-Chee Tseng, General Co-Chair

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Ron Shmelkin, Technion – Israel Institute of Technology, Israel
Yishai Zusman, Technion – Israel Institute of Technology, Israel

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Chaima Ghribi, Institut-Mines Telecom, France
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Rakesh Shrestha, Yeungnam University, Korea
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Sven van der Meer, Ericsson, Ireland
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Ricardo Bianchin Gomes, Federal University of Santa Maria, Brazil
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Fernando Gomes Moro, Federal University of Paraná, Brazil

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Christoph Meinel, University of Potsdam, Germany
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Karina Gomez, RMIT University, Australia
Sithamparanathan Kandeepan, RMIT University, Australia
Akram Al-Hourani, RMIT University, Australia
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Giovanni Russello, University of Auckland, New Zealand
Paul Zanna, Northbound Networks, Australia

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Davit Harutyunyan, FBK CREATE-NET, Italy
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Jose Villalon, University of Castilla–La Mancha, Spain
Antonio Garrido, University of Castilla–La Mancha, Spain

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Daniel Fernandes Macedo, Universidade Federal de Minas Gerais, Brazil
Luiz Filipe Vieira, Marcos Vieira, UFMG, Brazil.

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Xuxia Zhong, Beijing University of Posts and Telecommunications, China
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Adaptively Scaled Back-off (ASB) mechanism for Enhanced Performance of CSMA/CA in IEEE 802.11ax High Efficiency WLAN

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***Abstract*—This paper proposes an adaptively scaled back-off (ASB) mechanism to mitigate the performance degradations in the Binary Exponential Back-off (BEB) of IEEE 802.11 CSMA/CA in the highly dense environment such as IEEE 802.11ax high efficiency WLAN (HEW). The proposed ASB mechanism selects the optimal *CW* size to achieve maximized network performance adaptively based on the measured conditional collision probability (p_c) and the estimated number of contending stations. The ASB protocol can provide higher efficiency than the legacy Binary Exponential Back-off (BEB) that simply adjust the back-off contention window (*CW*) size by blind exponential increase at repeated collision avoidance and resetting to the minimum value (CW_{min}) at successful transmission. The performance analysis of the proposed ASB scheme with ns-3 network simulation shows that the proposed ASB scheme can achieve 21.14% higher throughput and take 32.45% less average interval between successful transmissions than the BEB mechanism in highly dense WLANs with saturated traffic environment.[1]**

Index Terms*— Contention window, CSMA/CA, IEEE 802.11ax, MAC, WLAN.

I. INTRODUCTION

The widely deployed IEEE 802.11 wireless local area networks (WLANs) are facing some fundamental challenges in performance in dense user environment, because of the blind binary exponential backoff (BEB) in the carrier sense multiple access with collision avoidance (CSMA/CA). The BEB simply exponentially doubles the congestion window (CW) value at collisions in order to avoid repeated collisions, while it always resets the CW value to be the minimum CW (CW_{min}) after a successful transmission, based on a blind assumption of low-level network congestion. As a result, the BEB scheme in current CSMA/CA does not provide optimized throughput in highly dense network environments such as IEEE 802.11ax high efficiency WLAN (HEW) [1, 2].

Many research works [3-9] have proposed modifications to the BEB-based CSMA/CA. In [3], an enhanced collision avoidance (ECA) was proposed that prevents the resetting of *CW* to its minimum value after each successful transmission, In the ECA, a deterministic back-off value is utilized instead of resetting the CW to CW_{min} after successful transmission, providing a collision-free scheduling for successful STAs. More detailed analysis for both saturated and non-saturated traffic conditions were presented in [4-6] with some more in-depth study. In the ECA, the STA that successfully transmitted, can use the same deterministic value in their next transmission attempt; therefore, the behavior of the system becomes deterministic and collision may be disappeared [5]. However, the ECA is analyzed to be efficient only at low dense networks until the number of STAs is less than the deterministic cycle length$((CW_{min}+1)/2)-1$.

In [7], an Exponential Increase Exponential Decrease (EIED) back-off mechanism was proposed, where the CW size is doubled after every unsuccessful transmission by collision, and is divided the by a fixed value of $\sqrt{2}$ after each successful transmission. Although the gentle decrease of back-off in EIED mechanism reduces the collision probability, it adjusts the CW value in fixed doubling at collisions and fixed decreasing $\sqrt{2}$ at successful transmissions, without providing an adaptive adjustment of CW values to select the optimal back-off CW considering the network congestion level. Therefore, it suffers from a low throughput performance in highly dense environment.

In this paper, we propose an adaptively scaled back-off (ASB) mechanism that can provide an enhanced throughput with lowest possible packet delay more than the current BEB in IEEE 802.11 CSMA/CA. This performance enhancement is achieved mainly by adaptive adjustments of the CW value considering the network congestion level. The adaptive increase/decrease of the CW value is controlled by the conditional collision probability (p_c) and the estimated number of contending STAs (*n*) in the WLAN, rather than blind exponential increase at collisions and resetting to the CW_{min} at successful transmissions. We utilize the Extended Kalman filter in the estimation of the number of competing STAs in an 802.11 network that was proposed by G. Bianchi *et al.* [8].

The remainder of the paper is organized as follows. Section II describes the related work. The proposed ASB mechanism is presented in detail in Section III. The ns-3 network simulation-based performance evaluations of the proposed ASB mechanism are explained in section IV, followed by conclusions in Section V.

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II. RELATED WORK

In this section, we explain and compare the basic mechanism of BEB, ECA, EIED, and ASB, as depicted in Algorithm 1 that provides the overall procedure of the adjustments of the CW value at each collision or successful frame transmission.

When a STA joins in the contention, the BEB mechanism initializes the retry counter (r) and the back-off stage counter (s) to zero. The back-off value (k) is initialized using a uniform random distribution and the minimum $CW\ (CW_{min})$. At each collision, the retry attempt counter (*r*) and the back-off stage counter (s) are increased. Because of the increased back-off stage, a larger contention window is used. Note that there is a maximum back-off stage $(maxB)$ and a maximum retry limit $(maxR)$ specified by the protocol. When the number of re-transmission attempts (*r*) on a packet reaches the maximum retry limit $(maxR)$, the packet is discarded. Furthermore, r and s are reset to zero, and a new back-off value (k) is computed when the retry limit is reached to the *maxR* or when the transmission is successful. The BEB increases the CW value upon collision as shown in line 22, and decreases the CW value at successful as shown in line 38 in Algorithm 1, respectively.

The Enhanced Collision Avoidance (ECA) behaves similarly to the current BEB in CSMA/CA protocol with an exception that a deterministic back-off is chosen after successful transmissions. The deterministic back-off value after each successful transmission is a key parameter of the ECA since it is the maximum number of STAs that can be accommodated in the collision-free mode in the CSMA/CA. The ECA can provide a collision-free environment to the WLAN only if the number of STAs is limited to the deterministic cycle length $((CW_{min}+1)/2)-1$. The ECA only focuses the back-off changes after the successful transmission, while the CSMA/CA performance is mainly affected by the collisions. The implementation of ECA is depicted at Lines 22 and 36 in Algorithm 1.

In EIED, the *CW* size is increased by the back-off factor r_I if a packet is collided by other transmissions, and the *CW* size is decreased by the back-off factor r_D if a packet was transmitted successfully. The performance of EIED is affected by the choice of the values of r_I and r_D. The authors have proposed to use $r_I = 2$ and $r_D = \sqrt{2}$ to achieve the better performance as compared to the BEB. Lines 24 and 40 of Algorithm 1 as depicted in the implementation of the EIED mechanism. Although the gentle decrease of back-off in EIED mechanism reduces the collision probability, since it adjusts the CW value in fixed ratios without providing an adaptive adjustment of CW values to select the optimal back-off *CW* considering the network congestion level, it suffers from a low throughput performance in highly dense environment.

III. ADAPTIVELY SCALED BACK-OFF (ASB) MECHANISM

The proposed ASB adjusts the *CW* value according to the conditional collision probability (p_c) and the estimated number of contending STAs (*n*), with gentle increment/decrement of *CW* value using an adaptively scaled back-off mechanism to avoid unnecessary time spent in back-off procedures. The extended Kalman Filter is used to calculate the channel collision probability based on the observed busy back-off slots, and the estimates the contending STAs within the WLAN. The rationale of using the Extended Kalman filter has threefold. First, it permits adaptively faster adjustment of the estimation of STAs with continuous variations in the WLAN. Second, it provides significantly enhanced accuracy of the estimation, by exploiting the variance of the measurements of p_c, whereas this information cannot be included in other elementary estimation approaches. Third, it is less complex to implement, and the use of this filtering technique does not have practical drawbacks.

The STA keeps observing the back-off procedure by selecting the k slots. The back-off value (k) is decreased by one if the channel is sensed to be idle. On the other hand, the back-off value (k) remains unchanged (freeze) if the medium is busy. Therefore, if the STA counts the number of times when k is frozen due to the busy channel, it can easily determine the number of busy slot (f_b). Also the STA can obtain the number of failed transmissions (f_c). Based on the number of busy slot $(f_b)$and the number of failed transmissions (f_c) at each observed back-off slots $(bSlot)$ interval, each individual STA can easily measure the conditional collision probability p_c by Eq. (1) [8]:

$$p_c = \frac{(f_b + f_c)}{bSlot} \tag{1}$$

In the calculation of p_c at line 26 of Algorithm 1, the value of f_c becomes 1, because the p_c is measured after each collision and only one collision is happened before the calculation. The number of observed busy slot (f_b) is increased at line 11, and the number of collision (f_c) is set to 1 at line 18 when STA observes the channel as busy and collision, respectively. Although the duration of frame transmission is not constant (that is the duration of frozen channel is much longer than idle channel), the average observed channel busy probability of the proposed ASB remains constant, because it is the number of busy slots (constant) out of the observed back-off slots (constant), which is assumed as the actual channel busy probability. The Fig. 1 shows the relation between the p_c and the number of STAs (*n*) with different maximum back-off stages $(maxB)$. As the number of STAs increase, the p_c increases because every time of the contentions and collisions increases with the increase of the number of STAs.

In the proposed ASB mechanism, the current *CW* size is not exponentially increased at transmission failures, but is adjusted adaptively by the scaling factor (S_{factor})that is obtained based on the estimated number of STAs (n) and the channel condition increase by Eq. (2):

$$S_{factor} = S_{factor} + ROUND\left[\frac{n \cdot p_c}{S_{factor}}\right] \tag{2}$$

where the $ROUND\left[{n \cdot p_c}/{S_{factor}}\right]$ is the smoothing relation for the adjustment of the S_{factor} to obtain an efficient *CW*.

As depicted at line 6 and line 36 in Algorithm 1, the S_{factor} is set to 1 at the initialization phase of each STA. The pervious S_{factor} is used in the next stage (s) after the collision, while it is reset to 1 after successful transmission. The changes of S_{factor} depends on the conditional collision probability p_c, the estimated number of contending STAs (n), and the previous value of the S_{factor}.

Algorithm 1. BEB, EIED, ECA, and ASB mechanism

```
1:  while the device is on do
2:    set $r = s = f_b = f_c = 0, maxR = 6, maxB = 5$
3:    set $CW_{min} = 31, CW_{max} = 1023$
4:    set $CW = CW_{min}, r_D = \sqrt{2}, r_I = 2$
5:    set $p_c = 0, n = \hat{n}$ // estimated according to [8]
6:    set $k = uniform\,(0, CW), bSlot = k, S_{factor} = 1$
7:    while packet is in queue do
8:      repeat:
9:        while $k > 0$ do
10:         if ChannelBusy then
11:           $f_b = f_b + 1$ //freeze back-off
12:         else
13:           $k = k - 1$     // wait one idle time slot
14:         end if
15:       end while
16:       Attempt to transmit one packet in the Tx queue
17:       if collision then
18:         $f_c = 1$          // $f_c$ is set to 1 after a collision
19:         $r = r + 1$
20:         $s = min(s + 1, maxB)$
21:         if $BEB$ or $ECA$ then
22:           $CW = min\left(\left(\left(2^s \cdot (CW_{min} + 1)\right) - 1\right), CW_{max}\right)$
23:         else if $EIED$ then
24:           $CW = min\left((r_I \cdot CW_{min}) - 1, CW_{max}\right)$
25:         else if $ASB$ then
26:           $p_c = (f_b + f_c)/bSlot$
27:           $S_{factor} = S_{factor} + ROUND\left[{}^{n \cdot p_c}/_{S_{factor}}\right]$
28:           $CW = min\left(\left(\left(S_{factor} \cdot CW_{min}\right) - 1\right), CW_{max}\right)$
29:         end if
30:         $k = uniform\,(0, CW)$
31:       end if
32:     until $(retry \le maxR)$ or $success$
33:     set $r = 0, s = 0, S_{factor} = 1, f_b = 0, f_c = 0$
34:     if $success$ or $(r > maxR)$ then
35:       if $ECA$ then
36:         $k = \left\lceil {}^{CW_{min}}/_{2} \right\rceil - 1$
37:       else if $BEB$ or $ASB$ then
38:         $CW = CW_{min}$
39:       else if $EIED$ then
40:         $CW = min\left(\left({}^{CW}/_{r_D}\right) - 1, CW_{max}\right)$
41:       end if
42:       $k = uniform\,(0, CW)$
43:     end if
44:   end while
45: end while
```

There are few basic changes in the ASB compared to the legacy BEB of CSMA/CA protocol. The ASB is similar to CSMA/CA at successful transmissions. The ASB, however, differs from the CSMA/CA in that the CW size is calculated by the multiplication of S_{factor} and CW_{min} at each collision. If the sender does not receive any acknowledgement (ACK) after sending a frame, the STA assumes that the transmission was failed because of a collision, and updates the CW value by Eq. (3):

$$CW = min\left(\left(CW_{min} \cdot S_{factor}\right), CW_{max}\right) \qquad (3)$$

The updates of the related parameters at a transmission failure by collision in the ASB mechanism are described at lines 26 ~ line 28 in Algorithm 1. If the STA successfully transmitted a frame, it resets the CW value to CWmin as depicted at line 38 in Algorithm 1. Note that at this point the size of CW is calculated based on the estimated conditional collision probability (p_c) and the estimated number of contending STAs (n). This particular estimation improves the network performance by avoiding unnecessary channel access delays.

TABLE I. MAC LAYER PARAMETERS USED IN SIMULATIONS

Parameters	Value
Operating Frequency	5 GHz
Bandwidth	20 MHz
Physical rate of the channel	6 Mbps
MAC header	24 bytes
MAC payload	1024 bytes
MAC tailer	4 bytes
PHY header	20 μs
Acknowledge (ACK)	14 bytes
Transmission range	10 meters
Minimum contention window (CW_{min})	16/32
Maximum contention window (CW_{max})	1023
Slot duration	9 μs
SIFS	16 μs
DIFS	60 μs
Propagation delay	1 μs
Maximum back-off stage $(maxB)$	5
Maximum retry limit $(maxR)$	6
Simulation time	100 s

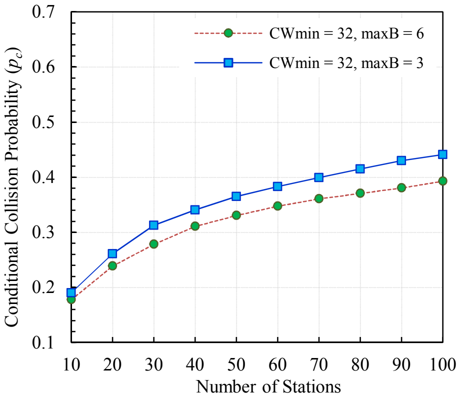
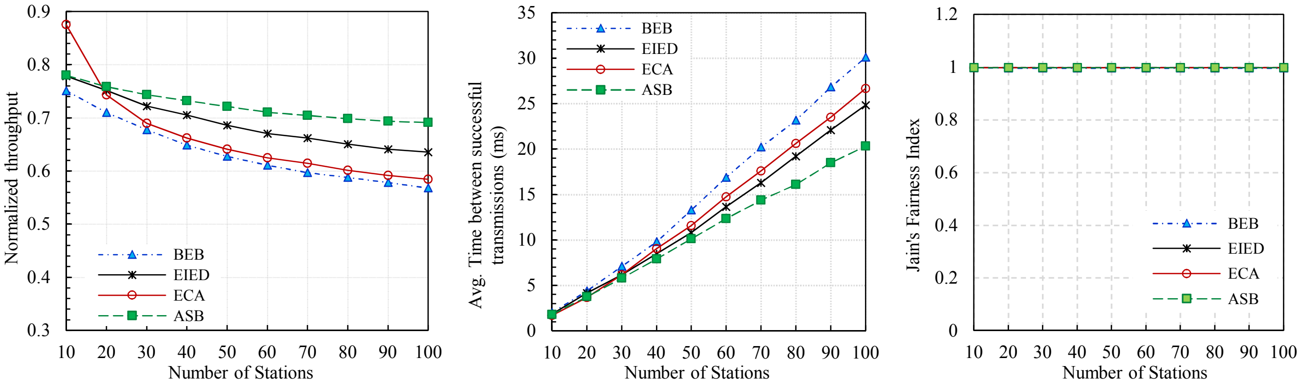


Fig. 1. Comparisons of increment of *CW* with the number of repeated collisions

IV. PERFORMANCE EVALUATION

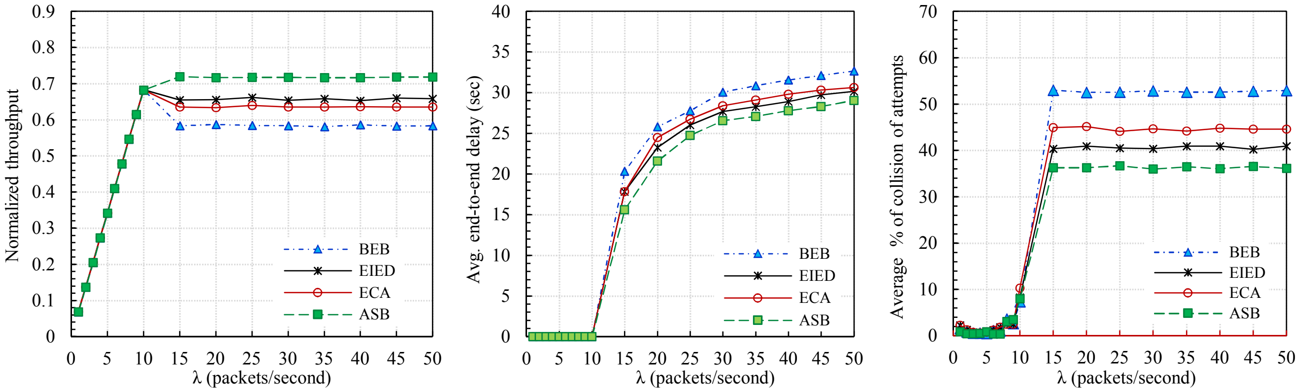
This section explains the simulation scenario and the parameters for the performance evaluations of the BEB, EIED, ECA, and the proposed ASB mechanism. Two different conditions have been considered: saturated and non-saturated. To evaluate and compare the four schemes with same conditions, a network of n STAs ranges from 10 to 100 is considered, where each STA is within the coverage area of the others without any hidden node problem. The simulations are performed in an event-driven simulator, network simulator-3 (NS-3) version 3.24 [9]. It was assumed that the physical wireless channel does not introduce any bit errors. The specific MAC and PHY layer parameters of the IEEE 802.11 ax High Efficiency WLAN (HEW) used in the simulations are listed in Table I.

Fig. 2 shows the performance under saturated condition. The normalized throughputs of the four protocols are compared in Fig. 2 (a). The ECA can achieve the collision-free operation if the number of contending STAs (n) is less than the deterministic cycle length, i.e., $n < ((CW_{min} + 1)/2) - 1$.



(a) (b) (c)

Fig. 2. Simulation results of different protocols under saturated traffic with ($CW_{min} = 32, CW_{max} = 1024, maxB = 6$): (a) Normalized throughput comparison, (b) Average time between successful transmission, (c) Jain's fairness index.



(a) (b) (c)

Fig. 3. Simulation results of different protocols under non-saturated traffic with ($CW_{min} = 32, CW_{max} = 1024, maxB = 6, n = 50$): (a) Normalized throughput comparison, (b) Average end-to-delay in sec, (c) Average percentage of collision of attempts.

This is why a sudden phase transition is observed at $n = 20$, if the number of STAs (n) is larger than the deterministic cycle length $((CW_{min} + 1)/2) - 1$.

Since EIED doubles the CW size at each unsuccessful transmission and divides the current CW size by $\sqrt{2}$ at each successful transmission, instead of resetting the CW to CW$_{\min}$ at the successful transmission, STA exponentially decreases the size so that unexpected collisions can be avoided, the throughput of the EIED remains higher than BEB. The ASB achieves around 21.66% higher throughput than BEB at 100 STAs. However, ASB provides moderate performance under light traffic. Fig. 2(b) shows the average time between successful transmissions. The average time between successful transmissions of proposed ASB is about 32.45% less than BEB in 100 STAs. Fig. 2(c) shows the Jain Fairness Index [11] of different protocols. We can see that all protocols have a near-perfect fairness performance.

In Fig. 3, the four schemes are evaluated based on non-saturated traffic with 50 STAs. Every STA generates λ packets/second, where λ is configured as 1 ~ 50. In Fig. 3(a), the normalized throughputs are same for all schemes up to 10 STAs. After that, the channel becomes saturated due to the higher frame transmission rate and the BEB faces severe packet drops, while the ASB performs better in the saturated traffic environment as well. A lower average end-to-end delays are observed in ASB as depicted in Fig. 3(b), due to its optimized adaptive usage of contention window size. Fig. 3(c) compares the average number of collisions for a transmission attempt, and the proposed ASB shows the lowest value.

V. CONCLUSION

In this paper, we proposed an adaptively scaled back-off (ASB) mechanism as a good substitution of the Binary Exponential Back-off (BEB) of CSMA/CA in IEEE 802.11ax high efficiency WLANs (HEW). The proposed ASB mechanism adaptively selects the optimal congestion window (CW) size to achieve optimized network performance based on the measured conditional collision probability and the estimated number of contending stations. The performance has been evaluated by ns-3 network simulations. Compared to the BEB scheme of CSMA/CA, the proposed ASB offers an enhanced performance in terms of both throughput and delay, while preserving fairness among the STAs. In the highly dense conditions, the ASB provides up to 21.14% higher throughput and 32.45% lower average time between successful transmissions for 100 STAs due to its optimized scaling procedure. In fact, with the increased contending STAs, a steady state situation can be reached instead of further decrease in performance in a distributed manner due to adaptive change in CW. The analysis results indicate that the performance of the proposed ASB mechanism relatively increases with increased number of contending STAs, compared to the existing schemes. All these properties ensure the ASB to be a good candidate for the upcoming IEEE 802.11ax High Efficiency WLAN (HEW).

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