# Channel observation-based scaled backoff mechanism for high-efficiency WLANs

R. Ali, N. Shahin, Y.-T. Kim, B.-S. Kim and S.W. Kim✉

A channel observation-based scaled backoff (COSB) mechanism for the carrier sense multiple access with collision avoidance of high efficiency wireless local area networks (WLANs) is devised. The proposed protocol modifies the blind scaling of contention window ($W$) in binary exponential backoff (BEB) scheme of currently deployed WLANs. COSB is employed to adaptively scale-up and scale-down the $W$ size during the backoff mechanism for collided and successfully transmitted data frames, respectively. It can achieve higher throughput and shorter delay compared to the conventional BEB mechanism in highly dense WLANs.

*Introduction:* Currently, wireless local area network (WLAN) medium access control (MAC) protocols primarily focus on maximising the communication channel utilisation through fair MAC layer resource allocation [1]. The binary exponential backoff (BEB) scheme is the typical and traditional carrier-sense multiple-access with collision avoidance (CSMA/CA) mechanism introduced in IEEE 802.11 DCF [1]. However, this scheme induces the performance degradation because the contention window ($W$) size of the station (STA) with consecutive unsuccessful transmissions is much larger than that of the STA with the successful transmission in this scheme, which makes it less likely to access the medium. Particularly for a network with a heavy load, resetting $W$ to its initial value $W_{\min}$ after successful transmission will result in more collisions and poor network performance. Similarly, for fewer contending, STAs, the blind exponential increase of $W$ for collision avoidance causes an unnecessarily long delay. Thus, the current BEB protocol does not allow WLANs to achieve high efficiency in highly dense environments.

To solve the performance degradation issue caused by the blind increase/decrease of BEB, a more adaptive practical channel observation-based scaled backoff (COSB) mechanism is proposed in this Letter, which mainly depends upon the density of the WLAN. The COSB guarantees high throughput and low delay by reducing the number of collisions during the channel access mechanism in both saturated and unsaturated traffic environments. An analytical model is also formulated to affirm the performance evaluation of COSB scheme.

*COSB scheme:* In the proposed COSB protocol, after the communication medium has been idle for a distributed inter-frame space (DIFS), all the STAs competing for a channel proceed to the backoff procedure by selecting a random backoff value $B$ as shown in Fig. 1.

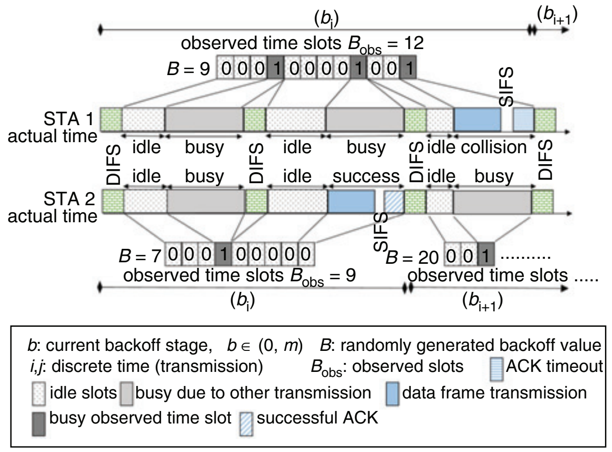


**Fig. 1** *Channel observation mechanism of COSB during the backoff procedure*

The time immediately following an idle DIFS is slotted into observation time slots ($\alpha$). The duration of $\alpha$ is either a constant slot time $\sigma$ during an idle period or a variable busy (successful or collided transmission) period. While the channel is sensed to be idle during $\sigma$, $B$ decrements by one. A data frame is transmitted after $B$ reaches zero. In addition, if the medium is sensed to be busy, the STA freezes $B$ and continues sensing the channel. If the channel is again sensed to be idle for DIFS, $B$ is resumed. Each individual STA can proficiently measure channel observation-based conditional collision probability $p_{obs}$, which is defined as the probability that a data frame transmitted by a tagged STA fails. We discretise the time in $B_{obs}$ observation time slots, where the value of $B_{obs}$ is the total number of $\alpha$ observation slots between two consecutive backoff stages as shown in Fig. 1. A tagged STA updates $p_{obs}$ from $B_{obs}$ of the backoff stage $b_i$ at the $i$th transmission as, $p_{obs} = (1/B_{obs}) \times \sum_{k=0}^{B_{obs}-1} S_k$, where for an observation time slot $k$, $S_k = 0$ if $\alpha$ is empty (idle) or the tagged STA transmits successfully, while $S_k = 1$ if $\alpha$ is busy or the tagged STA experiences collision as shown in Fig. 1. In the figure, STA 1 randomly selects its backoff value $B = 9$ for its $b_i$ backoff stage. Since STA 1 observes nine idle slot times, two busy periods, and one collision ($B_{obs} = 9 + 2 + 1 = 12$), $p_{obs}$ is updated as $((2+1)/B_{obs}) = (3/12) = 0.25$ in the next backoff stage $b_{i+1}$.

According to the channel observation-based conditional collision probability $p_{obs}$, the adaptively scaled contention window value is $W_{b_{i+1}}$ at backoff stage $b_{i+1}$ of the transmission time $i+1$, where $b_{i+1} \in (0, m)$ for the maximum $m$ number of backoff stages, and $i$ is the discretised time for the data frame transmissions of a tagged STA. More specifically, when a transmitted data frame has collided, the current contention window $W_{b_i}$ of backoff stage $b_i$ at the $i$th transmission time slot is scaled-up according to the observed $p_{obs}$ at the $i$th transmission, and when a data frame is transmitted successfully, the current contention window $W_{b_i}$ is scaled-down according to the observed $p_{obs}$ at the $i$th transmission. Unlike the BEB (where backoff stage is incremented for each retransmission and resets to zero for a new transmission as shown in Fig. 2*a*), the backoff stage $b_i$ in COSB at the $i$th transmission has the following property of increment or decrement:

$$b_{i+1} = \begin{cases} \min[b_i + 1, m], & \text{collision at } i\text{th transmit} \\ \max[b_i - 1, 0], & \text{success at } i\text{th transmit} \end{cases} \tag{1}$$

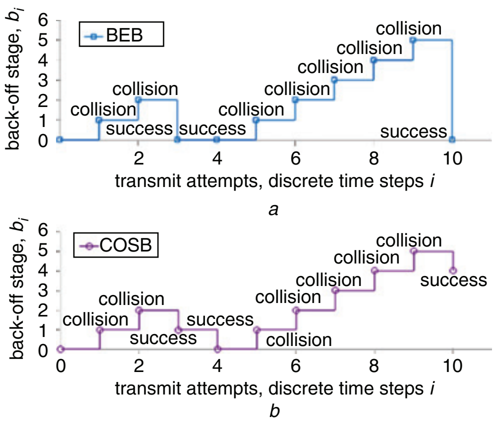


**Fig. 2** *Backoff stage after collision/successful transmission*

*a* Backoff stage increment/reset in BEB
*b* Backoff stage increment/decrement in COSB

Fig. 2*b* shows that the backoff stage does not reset after a successful transmission. Since the current backoff stage represents the number of collisions or successful transmissions of a tagged STA, it helps to scale the size of $W$ efficiently. The incremented or decremented backoff stage $b_i$ results in scaling-up or scaling-down of the current contention window, respectively. The scaling-up and scaling-down of the contention window operate as follows:

$$W_{b_{i+1}} = \begin{cases} \min\left[2^{b_{i+1}} \times W_{\min} \times \omega^{p_{obs}},\ W_{\max}\right], & \text{coll. at } i\text{th trans.} \\ \max\left[2^{b_{i+1}} \times W_{\min} \times \omega^{p_{obs}},\ W_{\min}\right], & \text{succ. at } i\text{th trans.} \end{cases}, \tag{2}$$

where $\omega$ is a constant design parameter to control the optimal size of the contention window and is expressed as $\omega = W_{\min}$.

*Transmission probability:* An analytical model for affirmation of the performance gain of proposed COSB is formulated. We obtain the transmission probability $\gamma$ of a tagged STA in COSB as follows:

$$\gamma = \frac{2}{\left(W + \beta W\left(\left(\sum_{b_i=0}^{m-1}(2\beta)^{b_i}\right)/\left(\sum_{b_i=0}^{m-1}(\beta)^{b_i}\right)\right) + 1\right)} \quad (3)$$

where $W = W_{\min} \times \omega^{p_{\rm obs}}$, and $\beta = (p_{\rm obs}/(1 - p_{\rm obs}))$. The $p_{\rm obs}$ for a tagged STA is that a transmitted data frame encounters a collision in a time slot, if at least one of the $n-1$ remaining STAs transmits, and can be obtained as $p_{\rm obs} = 1 - (1-\gamma)^{n-1}$. Once $\gamma$ and $p_{\rm obs}$ of a tagged STA are determined, the throughput and delay performance of the STA can be formulated using mathematical derivation in [2, 3].

*Numerical results:* We present simulation results using the NS3 simulator. A WLAN with operating frequency 5 GHz and bandwidth 20 MHz is used. The data frame payload is 1024 bytes. The MAC layer backoff parameters are used as; slot-time $\sigma = 9$ µs, minimum contention window $W_{\min} = 32$, maximum contention window $W_{\max} = 1024$, scaling design parameter $\omega = 32$. The number of contending STAs ($n$) ranges from 5 to 50. To evaluate the COSB, we compared simulation results with BEB, and two of the related contention window-scaling algorithms; enhanced collision avoidance (ECA) mechanism [4], and exponential increase-exponential decrease (EIED) backoff algorithm [5]. ECA uses a deterministic backoff value $B = W_{\min}/2$ instead of resetting $W$ to $W_{\min}$ after successful transmission. The $W$ value is exponentially increased after each unsuccessful transmission and is halved after each successful transmission in the EIED mechanism.

Fig. 3*a* describes the normalised throughput for a various number of STAs in a saturated traffic environment. In Fig. 3*a*, ECA performs better until $n < 15$, where the number of contenders is less than the deterministic cycle length $W_{\min}/2$ due to the collision-free deterministic environment. The performance of EIED is also limited to a short-term improvement due to blind increase and a decrease of $W$ size as shown in Fig. 3*a*. Whereas COSB provides increased throughput and a shorter average delay with increased density of the network as shown in Fig. 3. This performance enhancement of COSB comes from the adaptive channel observation-based scaling of $W$. Fig. 3 shows that the analytical model is accurate since analytical results (COSB-ana) match with the simulation results (COSB-sim) in both normalised throughput (Fig. 3*a*) and average delay (Fig. 3*b*).

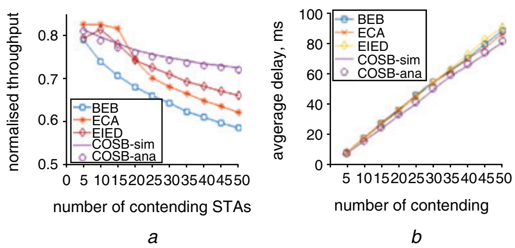


**Fig. 3** *Simulation results under saturated traffic environment*
*a* Normalised throughput
*b* Average delay (ms)

Fig. 4*a* presents the normalised throughput for various number of STAs in an unsaturated traffic environment with an offered load $\lambda = 35$ packets/sec. As shown in Fig. 4*a*, the normalised throughput increases linearly for all mechanisms until saturation is reached at approximately $n > 15$, where the throughput begins to decrease for BEB, ECA, and EIED, while COSB provides increased throughput until $n = 20$. A similar behaviour of the protocols can be seen in Fig. 4*b* for average delay. Figs. 4*c* and *d* show the normalised throughput performance of the protocols with a various offered load for $n = 10$ and $n = 30$, respectively. The figures show that the throughput of COSB depends on the saturation of the network. With fewer STAs (i.e. $n = 10$), the normalised throughput remains the same until the offered load reaches 50 packets/sec. After 50 packets/sec, the throughput of ECA and EIED is better than that of COSB. However, the performance degradation of ECA and EIED can be observed in comparison with COSB in Fig. 4*d* when the number of STAs is increased to $n = 30$.

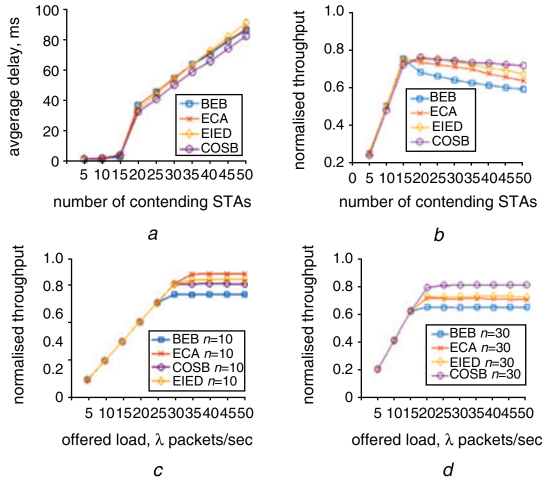


**Fig. 4** *Simulation results under an unsaturated traffic environment*
*a* Normalised throughput (offered load $\lambda = 35$ packets/sec)
*b* Average delay (offered load $\lambda = 35$ packets/sec)
*c* Normalised throughput ($n = 10$)
*d* Normalised throughput ($n = 30$)

*Conclusions:* In this Letter, we have described a suitable replacement to the prevalent BEB protocol used in the IEEE 802.11 DCF. The proposed COSB protocol offers enhanced performance in terms of throughput and delay for both saturated and unsaturated traffic conditions. Simulation results show that the COSB is more efficient than BEB for dense WLANs. An accurate analytical model affirms the performance improvement of proposed COSB.

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One or more of the Figures in this Letter are available in colour online.

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