

Optimized tuning of contention window for IEEE 802.11 WLAN

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Abstract

In wireless networks, the size of Contention Window (CW) plays a vital role as it changes the throughput and delay of the networks considerably. The proposed Collision Ratio based BackOff (CRBO) algorithm uses collision ratio to suggest CW updation after the successful and unsuccessful transmission events. This leads to proper scheduling of transmission when more than one node attempt to capture the shared medium. The strength of the proposed algorithm is analyzed using NS2 simulator in terms of throughput, delay, packet loss and fairness. The simulation results prove that the proposed algorithm outperforms the existing algorithms under heavy and low traffic in random and grid topology.

Keywords: Wireless networks, contention window, collision rate, backoff, NS2.

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1. Introduction

One of the most frequently used standards for Wireless networks is the IEEE 802.11 standard (Brenner, 1997). In a shared medium, in which all stations compete for access, and only one of the stations can transmit at any given instant of time. Moreover, if two or more stations attempt to send data packets at the same time, collision will happen and the packet is lost. In case of wireless networks, it is difficult to distinguish between collision of packets and external interference which leads to detecting collision highly complicated (Thorpe *et al*, 2014). But, the 802.11 standard defines the access mechanism of Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) and offers the Distributed Coordination Function (DCF). In DCF (Jochen, 2003), one of the most fundamental methods, all stations compete for the transmission medium. If a station finds the busy medium, back-off algorithm is executed to minimize collisions.

The DCF mechanism is as follows: If a station is about to send a packet, the smallest CW is taken and in case of a collision of the packet, the station chooses an exponentially increased CW. Such cases occur when there is heavy traffic i.e many stations access the shared wireless medium at the same physical location and time (Zhai *et al*, 2006). Once a station transmits its packet successfully, its back-off window is reset to the smallest size for future transmissions; but, this fares poorly in case of heavy traffic (Natkaniec *et al*, 2013). This paper tweaks this algorithm to some extent by changing the deciding factors and size of the contention window.

2. Literature Review

As mentioned in the previous section, the limitations of BEB are reduced by many enhanced algorithms proposed in the literature. Some of them along with demerits are discussed in the following paragraphs. Modified Algorithm for DCF (MADCF) under heavy traffic is proposed in (Elarbaoui *et al*, 2008). In this algorithm, the number of retransmissions is taken into account while calculating the contention window size after a successful transmission. If the number of retransmissions is greater than n, the contention window size is reset to W_n after a successful transmission else reverts to zero. Bharghavan *et al*. proposed a new algorithm in MACAW scheme termed as Multiple Increase and Linear Decrease (MILD) backoff algorithm (Bharghavan *et al*,

1994). In MILD, the CW size is multiplied with constant factor 1.5 instead of doubling it, when there is an unsuccessful transmission. After the successful transmission, CW size is decreased linearly by 1 instead of reset to 0. By this method, the collision probability is reduced and simulation result (Bharghavan *et al.*, 1994) shows that MILD is better than the BEB algorithm over large network.

Deng *et al.* (2004) proposed an algorithm called Linear Increase and Linear Decrease (LILD) (Deng *et al.*, 2004) which is an extension of MILD. This protocol follows the same principle as MILD when successful transmission, where as in case of unsuccessful transmission the algorithm updates CW by $CW + CW_{min}$ instead of multiplying by 1.5. It avoids the problem of slow linear change over failed transmission and provides good throughput for large network.

Deng *et al.* (2004) extended their work with new approach called Linear/Multiplicative Increase and Linear Decrease (LMILD) (Huang *et al.*, 2012) in which the failed nodes increases their CW multiplicatively while other neighbor nodes increases CW linearly. There is no packet reception during collision since each node uses an additional information which generates carrier sensing signal. In their study, LMILD outperforms BEB and MILD schemes in wide range of active nodes in networks. However, the above all algorithms focused on saturated traffic loads of wireless networks. Alkadeki *et al.* (2016) worked on non-saturated traffic loads and proposed dynamic control backoff time algorithm, implemented using Equilibrium Point Analysis (EPA) model. In DCBTA, low or heavy traffic load is determined using $CW_{threshold}$ value. Upon unsuccessful transmission, if the traffic load is low, then CW size is doubled as BEB algorithm whereas if traffic load is high, the CW size is incremented by $2 * CW + 2$ which decreases collision probability, thus increasing throughput. Huang *et al.* (2016) addressed poor network fairness of BEB and proposed new algorithm termed as synchronized contention window (SCW) –based backoff algorithm. When the channel state is changed, the contending stations are synchronized by resetting the CW. Hence, it guarantees that each station gets equal chance for channel access in next contention. Zhang *et al.* (2016) proposed a backoff algorithm based on self-adaptive contention window update factor. The algorithm modifies the updating factor of CW based on the current network load. They developed theoretical model using two dimensional Markov chain on backoff procedure.

The algorithm proposed by Kunho *et al.* (2012) measures optimized contention window in both saturated and unsaturated conditions. In saturated condition, CW size is estimated using channel busyness ratio to maximize the network throughput. Whereas in unsaturated condition, based on status of the current slot (idle or busy), two CW (WI and WB) values are determined to minimize the delay. Additionally, the protocol introduces the priorities in accessing the channel according to traffic classes. Bononi *et al.* (2004) proposed asymptotically optimal backoff that updates contention window size with respect to the current contention level by estimating the slot utilization and average size of transmitted frames. Measuring number of active stations accurately is difficult and hence the algorithm uses sampled p-persistent backoff interval from a geometric distribution with probability p. Each station updates the slot utilization in every backoff interval and uses an additional control parameter called probability of transmission before any transmission. The comparison of above mentioned algorithms is summarized in Table 1. It is inferred from the aforementioned discussion that updating CW value plays a predominant role in wireless network performance. By considering all these facts and drawbacks of existing algorithms as mentioned in Table 1, an adaptive collision Ratio based BackOff (CRBO) algorithm is proposed to enhance throughput and fairness by minimizing delay and packet loss.

3. Proposed Algorithm

The proposed CRBO algorithm intends to afford an efficient medium access control by proper scheduling of transmissions among competing stations. This algorithm uses collision ratio as a metric to indicate the network contention level in order to tune the pace of CW adjustments upon collisions and successful transmissions under heavy traffic network condition. To achieve this, every node keeps track of number of successful transmissions ($Tran_{Suc}$) and collided transmissions ($Tran_{Col}$). These two local information are readily available and also reliable. Each node can have these parameters from its own experience without using complex calculation and run time measurements. As a consequent, protocol overhead, processing time and energy consumption are minimized. With the aid of above mentioned static information, collision ratio as in (1) is calculated to determine the next CW size.

$$\text{Collision ratio} = \frac{Tran_{Col}}{Tran_{Col} + Tran_{Suc}} \quad (1)$$

This parameter correctly predicts the current network condition in heavily congested network. The higher collision ratio reveals high degree of contention and congestion in the network. In this situation, the difference between two consecutive CW sizes must be large enough to avoid further collisions. This will be achieved by faster CW increments. In other case, the lower collision ratio depicts less contention degree which requires adequate CW increments to avoid end to end delay. With these considerations, the proposed CW adjustments using eq(1) upon collisions and successful transmission are elaborated in the following subsections.

3.1 CW adjustments upon collisions: When a node experiences collision, collision ratio is examined. If it is less than threshold value, contention and congestion level in the network is under the controllable margin. In this case, CW needs to be incremented slowly to minimize end-to-end delay. The linear increment by the factor of 32 is recommended by the proposed CRBO algorithm and backoff time is chosen from the newly estimated CW range as shown in (2).

$$CW_{new} = \min (CW_{prev} + 32, Cw_{max}) \tag{2}$$

If collision rate is greater than the threshold value, it gives the sign of overloaded network condition. In this scenario, the immediate retransmissions need to be avoided to minimize the collision probability. Similar to BEB, the proposed algorithm exponentially increases CW size as shown in (3) to have larger CW range. As a result, CW size chosen from this expanded range is high which leads to longer waiting time. Moreover, from this enlarged CW range, the selection of similar CW size by more than one node is also effectively controlled. Hence the collision among competing stations is minimized.

$$CW_{new} = \min ((CW_{prev} \ll 1) + 1, CW_{max}) \tag{3}$$

Table 1. Comparison of Backoff Algorithms

Algorithm Name	CW increment upon collision	CW decrement upon success	No. of nodes & topology	Achieved enhancements	Problem/ Drawbacks	
MILD	$CW = \min(CW * 2, CW_{max})$	$CW = \max(CW - CW_{min}, CW_{min})$	4 - 40	Better than BEB	Suited for saturated traffic	
LILD	$CW = \min(CW + CW_{min}, CW_{max})$	$CW = \max(CW - CW_{min}, CW_{min})$	4 - 40	good quality for larger network	Suited for saturated traffic	
LMILD	$CW = \min(m_c * CW, CW_{max})$ $CW = \min(CW + l_c, CW_{max})$	$CW = \max(CW - l_s, CW_{min})$	128	better than BEB for large network (87% throughput)	Suited for saturated traffic	
DCBT A	L T	$CW = CW * 2$	$CW = CW - 1$	50 - 100	Throughput increase by 10% than BEB	Not considered different network environment
	H T	$CW = CW * 2 + 2$	$CW = CW - 2$	50 - 100	Throughput increase by 3% than BEB	
SCW	$CW = \min(CW_{max}, 2 * CW)$	$CW = \max(CW_{min}, CW / 2)$	4 - 40 Single-hop network	Fairness index nearly equal to 1 and suitable for dense stations	For small network the delay is increased.	
SACW	$CW = \min(c * CW_{old}, CW_{max})$	$CW = \max(CW_{old} / c, CW_{min})$	5 - 100	Better channel utilization	Fairness not addressed	
CCBCWA	For Saturated, $W_s = \begin{cases} W_0, & \text{if } \sum_{i=1}^k u_i = 0 \\ W_x \sum_{i=0}^k u_i, & \text{otherwise} \end{cases}$ For Unsaturated, $W_1 = \frac{\dagger}{Tb} W_B$		50	Better delay and throughput	1. Tested only for small size network 2. Did not differentiate transmission event	
AOB	Station transmit with probability $P-T(ACL(q), S-U, N-A) = 1 - \min(1, \frac{S-U}{ACI(q)})^{N-A}$ Otherwise, reschedule with probability $1 - P_T$		200	Increased channel utilization	1. Probabilistic way to tune CW size 2. Fairness not addressed	

3.2 CW adjustments after successful transmissions: Under heavy traffic condition, it is highly mandatory to adjust CW after having successful transmissions. As in BEB, if CW reverts to its minimum CW (CW_{min}), the following problems are unavoidable.
 (i) The stations which had successful transmission always preempts longer waiting stations. This leads to channel capture phenomenon.
 (ii) Newly entered stations and stations with successful transmissions may select the more or less same CW size from the limited CW range (0, CW_{min}). As a consequent, the collisions among these stations are inevitable.

- (iii) The difference between CW size of a new packet and a packet which faces many collisions leads to severe delay jitter.
- (iv) There is a high probability for service starvation in congested network.

To overcome above mentioned problems, several algorithms adopted different CW adjustments to be followed after successful transmission as discussed in Section 2. But the limitation in these algorithms is that the current network condition is not considered while estimating CW size. As depicted in Table 1, they decremented CW value either linearly or exponentially. To mitigate these difficulties, the proposed CRBO algorithm suggests CW updation based on collision rate.

As in BEB, CW resetting mechanism is utilized if the collision ratio is less than or equal to threshold value. The lesser collision ratio indicates the lesser number of active stations. In this case, the waiting time is chosen from the shorter range (0, CWmin) to minimize the channel access delay which further leads to higher network throughput and channel utilization. Otherwise, CW size is estimated as shown in the proposed eq (4).

$$CW_{new} = \max (CW_{min} * (2^{rc}) + 32, CW_{min}) \tag{4}$$

By using polynomial function of retransmission count (rc), the new CW size is determined. This forces the stations to wait for sufficient amount of time before immediately starting next transmissions. Meantime, the newly entered stations or stations with lesser waiting time may get the channel access. This leads to fairness among competing stations.

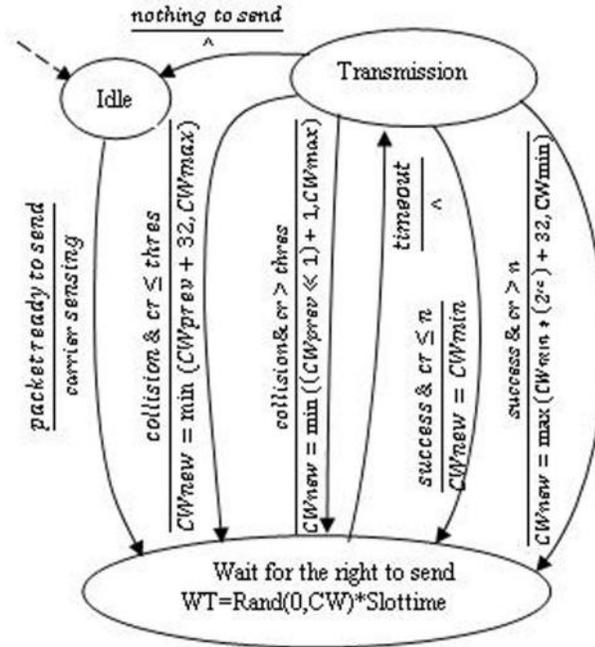


Figure 1. FSM diagram of Proposed Algorithm

The Finite State Machine (FSM) diagram for the proposed CRBO algorithm is shown in Figure 1. The event and the corresponding action are shown above and below the horizontal line respectively. If there is no corresponding event, then the symbol \wedge is used. Initially, node will be in the Idle state. If the node has packet to send, it goes to Wait for the right to send state. After the timeout event, it goes to Transmission state. Based on the status of transmission and collision ratio, CWnew value is chosen. The new waiting time (WT) is estimated according to this value as depicted in Figure 1. Once all the data have been transmitted, node goes to Idle state.

4. Simulation and Results

The focal points of this section are to assess the performance of the proposed CRBO algorithm through NS2 simulator (Teerawat et al, 2009) and compare the results with BEB and MADCF. The behavior of these three algorithms in terms of throughput, delay, and packet loss and fairness index are measured with varying number of nodes under random and grid topology. The scale of the random topology is varied from 80 nodes to 160 nodes with 10m/s as mobility speed. Since the nodes are freely moving, the random topology depicts the dynamic nature of wireless mobile network. Whereas in grid topology, a static wireless network is constructed with 49, 64, 81,100 and 121 nodes. To retain the structure of the topology throughout the simulation, node mobility is not imposed into the grid topology. Figure 2 and 3 show the NS2 screenshot of random and grid topology of 100 nodes

respectively. . In these screenshot, the circles are the transmission range and the arrowhead lines show the transmission directions of the corresponding node. In this simulation, high and low traffic patterns are considered to highlight the capability of the proposed CRBO algorithm. In high traffic scenario, almost 90% of the nodes are involved in active communication at any instant. But in low traffic, only 20 % of the nodes in the network are participating in the communication. As expected, the contention and congestion level in high traffic scenario is more than in low traffic scenario. In these two extreme cases, the proposed CRBO algorithm outperforms BEB and MADCF as depicted in the following sections. The other simulation parameters are listed in Table 2.

Table 2. Simulation Parameters

Parameters	Values
Area	1000 X 1000
Physical Layer & Antenna	DSSS & Omni directional
MAC protocol	802.11 DCF
Routing Protocol	AODV
Traffic type & Packet size	CBR & 512 bytes
Topology	Random & Grid topology
DIFS & SIFS	50µs & 10 µs
Slot time	20µs
Transmission Range	250m
Simulation time	180sec

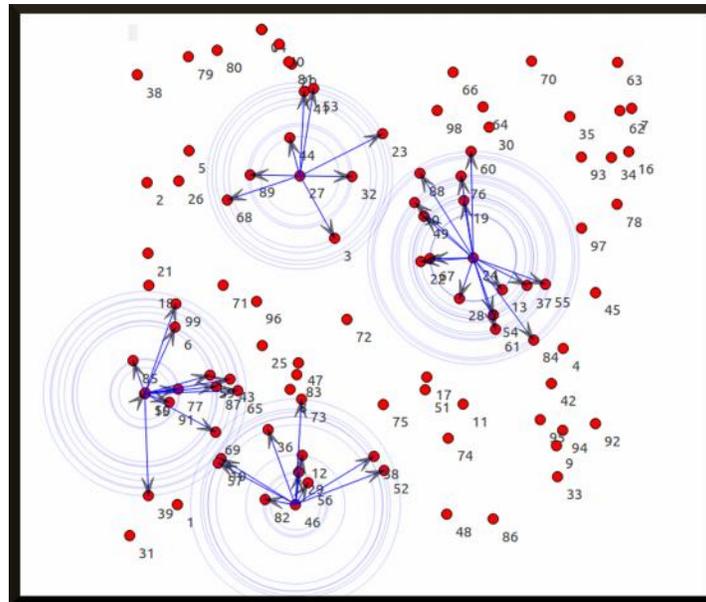


Figure 2. Random Topology with 100 nodes

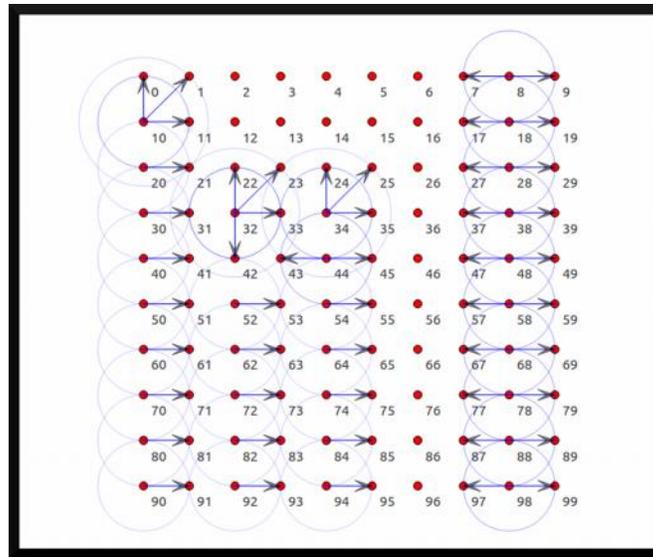


Figure 3. Grid Topology with 100 nodes

4.1 Throughput performance: Figures 4 and 5 show the throughput performance of BEB, MADCF and CRBO in random topology with varying number of nodes under high and low traffic scenario respectively. The throughput is also measured for these three algorithms in grid topology under two different traffic scenarios and which are given in Figures 6 and 7 respectively. It is inferred from these Figures that, the throughput performance depends on contention window size at different backoff stage. Irrespective of the topology and traffic type, the proposed CRBO algorithm performs well as compared the legacy BEB algorithm and MADCF. This is mainly due to the dynamic adaptiveness of the proposed algorithm to estimate CW size by considering the present status of the network. Collision ratio, one of the decision parameters in CRBO algorithm, reveals the degree of the congestion in the network. With the aid of this, the proposed algorithm updates CW size linearly in case of low congestion or exponentially in high congestion in the network. As a consequence, the waiting time to capture the idle medium is appropriately estimated to successfully transmit more number of packets or waiting for the idle medium without disturbing ongoing transmissions. This leads to high throughput by minimizing number of collisions among nodes. In addition to this, the proposed algorithm predicts CW size after having successful transmission. Unlike the resetting mechanism in BEB, the proposed CRBO utilizes the decision parameter, retransmission count, to determine the CW size. Due to this dynamic updation, the anomalies of resetting mechanism as mentioned in Section 3.2 are minimized thereby enhancing throughput performance in both the topologies.

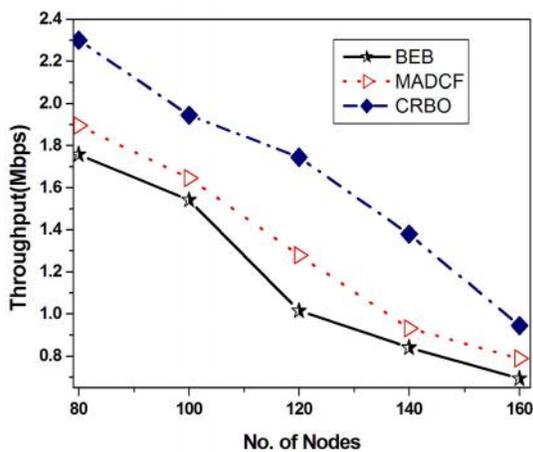


Figure 4. Throughput in Random topology under High Traffic

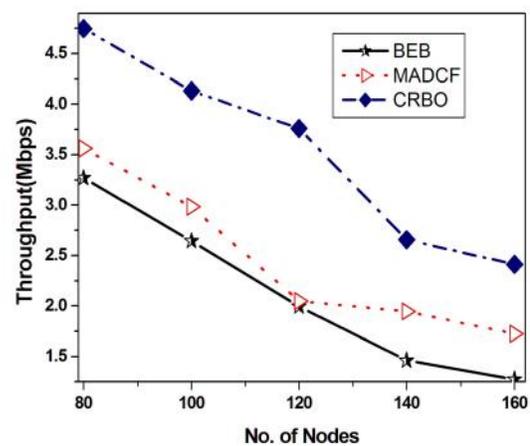


Figure 5. Throughput in Random topology under Low Traffic

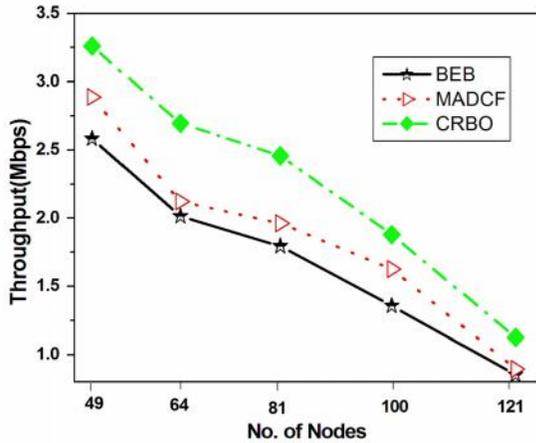


Figure 6. Throughput in Grid topology under High Traffic

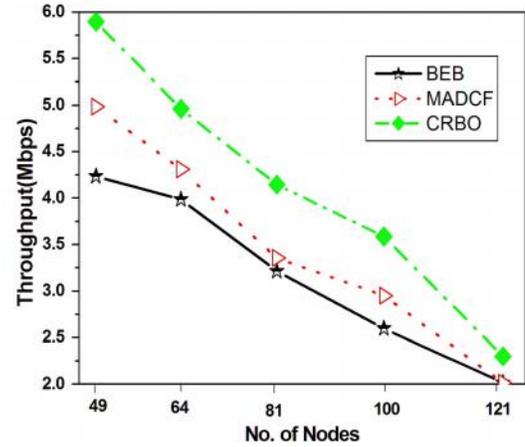


Figure 7. Throughput in Grid topology under Low Traffic

4.2 Delay performance: The end-to-end delay performance for each algorithm is measured in random topology and shown in Figures 8 and 9 under high and low traffic conditions respectively. Also in grid topology, delay is estimated under high and low traffic and shown in Figures 10 and 11 respectively. From these figures, it is deduced that BEB and MADCF algorithms have experienced high end-to-end delay as they exhibited long idle time after collisions (specifically at the end of backoff stages) which consequently increases delay. Whereas in the proposed CRBO algorithm, CW is updated either exponentially or linearly to reduce the unnecessary idle time as much as possible. Moreover, the CW adaptation after the successful transmission in the proposed algorithm helps to minimize the collision probability as it forces the nodes to wait before attempting the next unsafe transmissions. As a result the time taken for a packet to travel from one station to another station decreases thereby minimizing end-to-end delay under different traffic patterns.

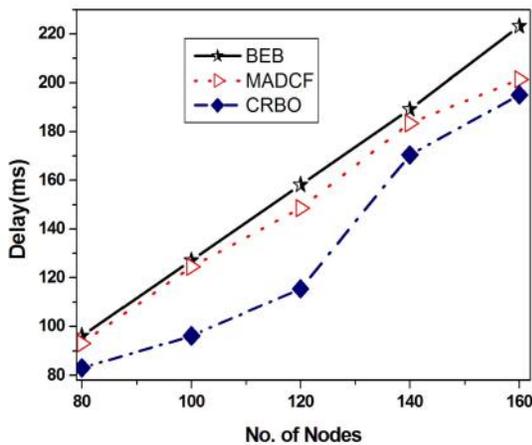


Figure 8. Delay in Random topology under High Traffic

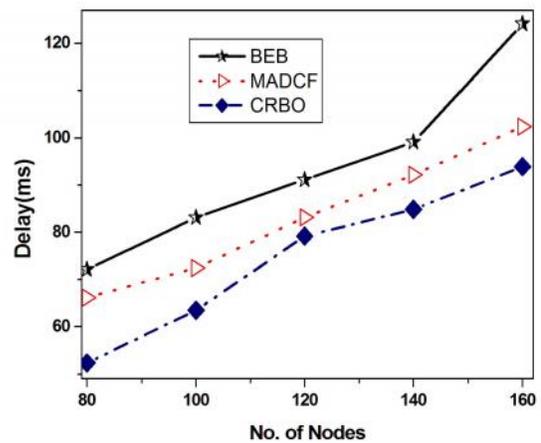


Figure 9. Delay in Random topology under Low Traffic

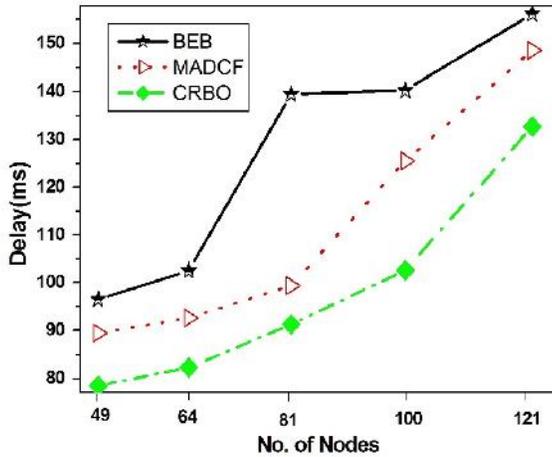


Figure 10. Delay in Grid topology under High Traffic

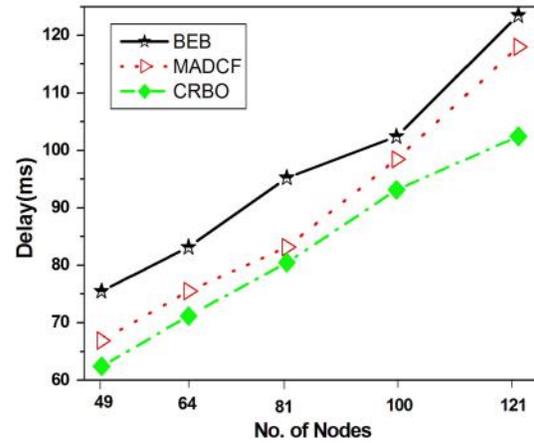


Figure 11. Delay in Grid topology under Low Traffic

4.3 Packet loss performance: The packet loss parameter is calculated as the ratio of the number of packets dropped to the number of total packets sent. The collision rate is related to the packet loss ratio since the number of packets dropped are an indirect measure of the number of collisions in the system. Figures 12 and 13 show the packet loss incurred by BEB, MADCF and CRBO algorithms in random topology under heavy and low traffic respectively. As depicted in these figures, packet loss is increased as the number of active contending stations are increased. Figures 14 and 15 reveal the packet loss performance of these algorithms in grid topology under high and low traffic respectively. It is inferred from these figures that the packet loss ratio is more in random topology as it incorporates node mobility than in grid topology. However, the proposed CRBO algorithm performs better than the legacy BEB and MADCF. In the proposed CRBO algorithm, each node is assigned the appropriate CW size according to collision ratio and retransmission count. So the probability of selecting the same contention window size by more than one node is minimized thereby ensuring different waiting time assigned to the stations. This guarantees either the successful transmission or defer from accessing the busy medium to minimize collisions as legacy BEB and MADCF.

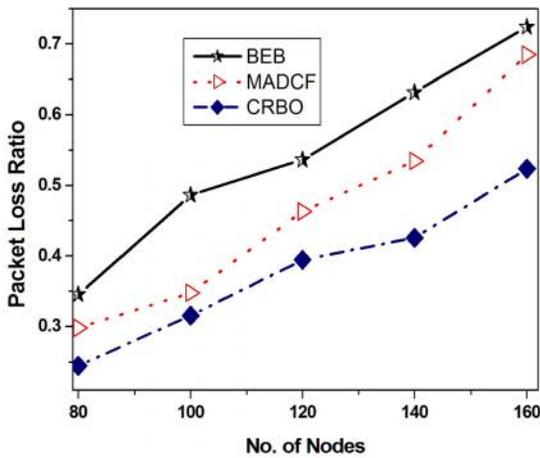


Figure 12. Packet loss in Random topology under High Traffic

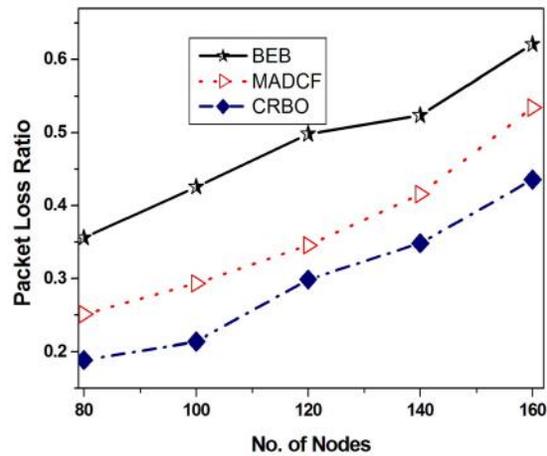


Figure 13. Packet loss in Random topology under Low Traffic

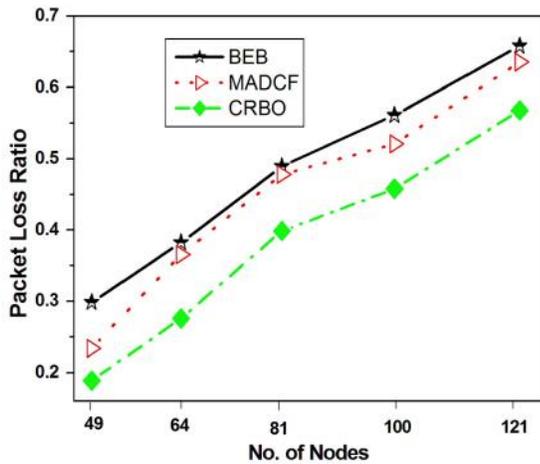


Figure 14. Packet loss in Grid topology under High Traffic

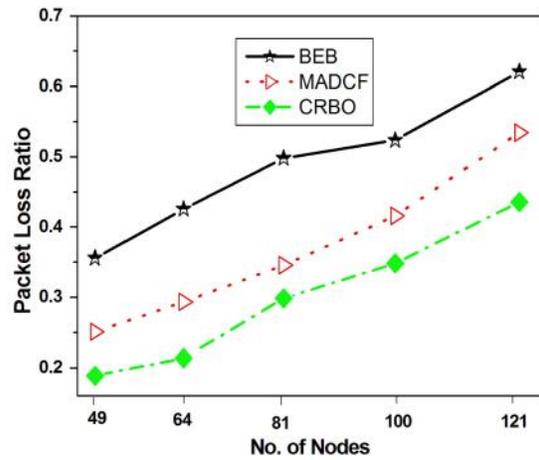


Figure 14. Packet loss in Grid topology under Low Traffic

4.4 Fairness Index performance: The fairness index measure is used to determine whether the stations are receiving a fair share of the system resources. The Jain’s fairness index equation in (5) (Jain et al,2016) is given by ,

$$J(x_1, x_2, \dots, x_n) = \frac{\left(\sum_{i=1}^n x_i\right)^2}{n * \left(\sum_{i=1}^n x_i^2\right)} \quad (5)$$

Using the above equation, the fairness index attained by BEB, MADCF and the proposed CRBO algorithms are measured in random and grid topology under high and low traffic scenarios. These are given in Figures 15, 16, 17 and 18. From these figures, it can be stated that the proposed CRBO algorithm achieves better fairness index than the legacy BEB and MADCF algorithm. One of the main reasons is that adjusting CW size after having successful transmission instead of resetting CW size to its minimum value. This dynamic adjustment of CW is stimulated by collision rate and retransmission count. As a consequence, stations that had successful transmission will not preempt the longer waiting station thereby leading to fair allocation of medium among competing nodes.

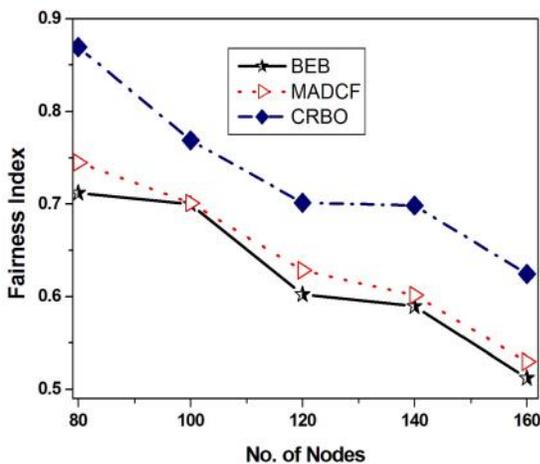


Figure 15. Fairness index in Random topology under High Traffic

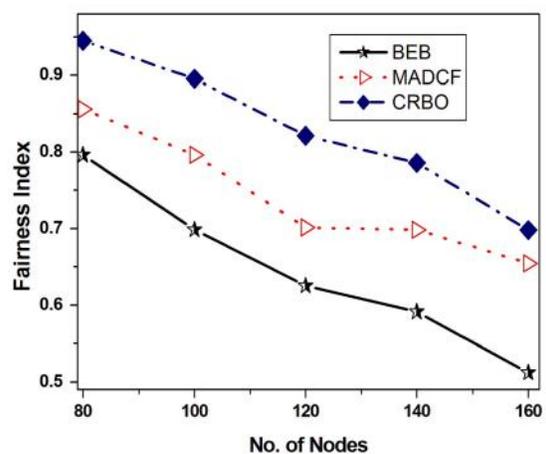


Figure 16. Fairness index in Random topology under Low Traffic

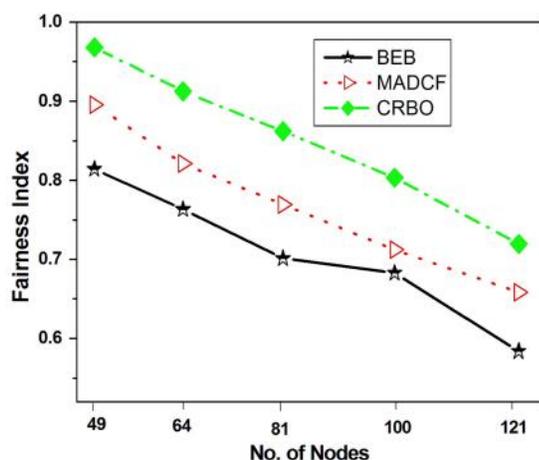


Figure 17. Fairness index in Grid topology under High Traffic

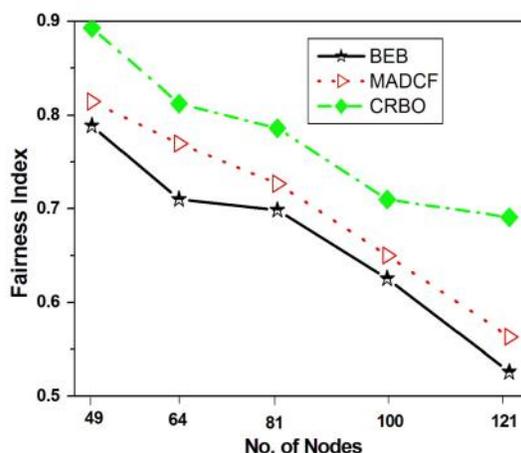


Figure 18. Fairness index in Grid topology under Low Traffic

4. Conclusion

This paper has proposed CRBO algorithm to enhance the network performance under heavy and low traffic in the random and grid network topology. In the proposed algorithm, CW is incremented either exponentially or linearly based on collision rate. In case of successful transmission, the resetting or polynomial CW adjustment based on retransmission count is adopted. These dynamic adaptations of CW in the proposed algorithm guarantee more efficient resource utilization by minimizing delay and packet loss. The possible extension of the proposed algorithm is to use cross layer information to better distinguish the wireless environment and according to that CW size may be changed. From the physical layer, Signal to Interference Noise Ratio (SINR) information can be utilized to estimate the channel quality. This piece of information can be utilized by the proposed algorithm for better scheduling of transmissions with minimum of overhead.

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