TOWARDS A COLLISION FREE MEDIUM ACCESS FOR QOS SUPPORT IN WLAN

A Dissertation Submitted in Partial Fulfillment of Requirement for The Degree of Bachelor of Science in Technical Education in Computer Science and Engineering

Islamic University of Technology (IUT)
A subsidiary organ of Organisation of Islamic Cooperation(OIC)

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Abstract:

This paper presents an analysis of the IEEE 802.16e MAC overhead in case of WLAN. The influence of several parameters is examined. The parameters, such as the number of subscribed stations in the network, The Quality of Service(QOS), various modulation and coding for different MAC protocols, the back-off window size and length of MAC PDUs are assigned as the overhead parameter. The results show these parameters have significant impact on the efficiency of MAC layer. Finally, some recommendations to reduce the overhead and moving towards a collision free medium access for QoS support in WLAN

Keywords:

MAC, EDCA, Backoff, OFDMA, TDMA, Deterministic, QoS.

Introduction:

In IEEE 802.11 based WLAN standard, distributed coordination function is the fundamental medium access control (MAC) technique. It employs a CSMA/CA with random binary exponential back-off algorithm and provides contention-based distributed channel access for stations to share the wireless medium. However, performance of this mechanism drops dramatically due to random structure of the back-off process, high collision probability and frame errors. That is why development of an efficient MAC protocol, providing both high throughput for data traffic and quality of service (QoS) support for real-time applications, has become a major focus in WLAN research.

Several distributed protocols embrace randomization to achieve arbitration. In WiFi networks, for example, each participating node picks a random number from a specified range and begins counting down. The node that finishes first, say N1, wins channel contention and begins transmission. The other nodes freeze their countdown temporarily, and revive it only after N1's transmission is complete. Since every node counts down at the same pace, this scheme produces an implicit ordering among nodes. Put differently, the node that picks the smallest random number transmits first, the one that picks the second smallest number transmits second, and so on. The overall operation is often termed as "back-off".

While back-off arbitrates channel contention, it incurs a performance cost. Specifically, when multiple nodes are simultaneously backing off, the channel must remain idle, naturally leading to under-utilization. Moreover, network congestion prompts an exponential increase in the back-off range, introducing the possibility of greater channel wastage.

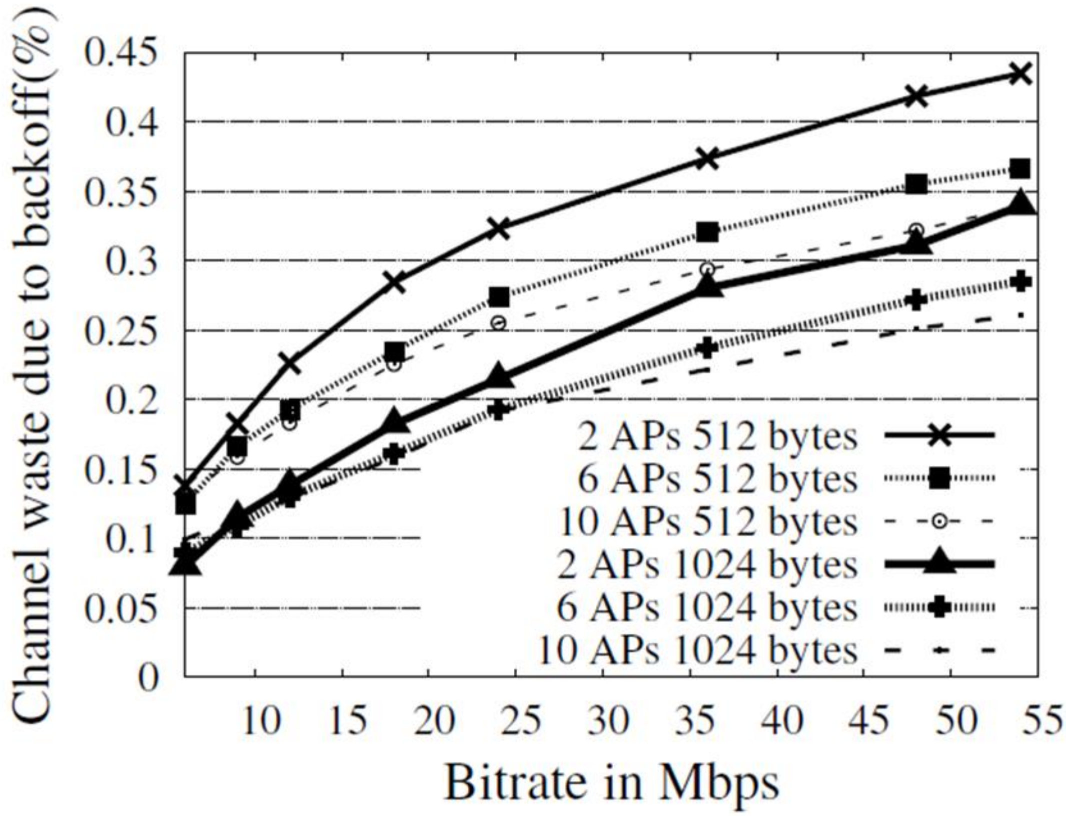


Figure 1: Overhead of 802.11 backoff. Larger fraction of channel wasted with smaller packets at high bitrates.

Recent years have witnessed a rapid growth of ubiquitous applications in the Internet with a vast spread of multimedia streams. This makes providing differentiated quality of service (QoS) for such applications in Wireless Local Area

Networks (WLANs) very challenging task. Besides, several wireless technologies have been risen from amongst them IEEE 802.11 has assumed as a de facto standard in WLANs due to some of its key features like deployment flexibility, infrastructure simplicity and cost effectiveness [18]. In IEE 802.11 WLANs, the QoS of multimedia communications cannot be efficiently achieved due to frequent

collisions and retransmission [17]. IEEE 802.11 introduces two channel access modes, namely Distributed Coordination Function (DCF) and Point Coordination Function (PCF). The former is the mandatory medium access method which is

appropriate to serve best effort applications such as HTTP, FTP and SMTP. Multimedia streams that require a certain QoS level are served during the controlled mode (i.e. PCF) since it provides a contention-free polling-based access to the channel to provide the demanded QoS. However, due to the fact that PCF only operates on the Free-Contention period, which may considerably cause an increase in the transmission delay, especially with high bursty traffics it considered not efficient for serving the applications that required high QoS constraints. Therefore, IEEE 802.11 Task Group e (TGe) has established IEEE 802.11e protocol [20] which then introduced a revised version [19] with new technical enhancements on MAC and Physical layer.

The QoS support of IEEE 802.11 standard has been extended in IEEE 802.11e by means of hybrid coordination function (HCF). Enhanced distributed channel access

function (EDCF) which extends DCF, provides a prioritized QoS throughout its distributed access manner to the wireless medium. HCF controlled channel access (HCCA) which extends PCF that works based on a centralized polling mechanism

to provide differentiated service, according to rigid QoS parameters negotiated with the centralized coordination (HC). EDCA introduces a random access to the wireless medium by means of access categories (ACs). The traffics are mapped to ACs according to their priority. Every AC will be associated with a back-off timer so that the highest priority ACs will go through a shorter back-off process. Despite EDCA provides QoS support, it is still not efficient for application with rigid QoS requirements.

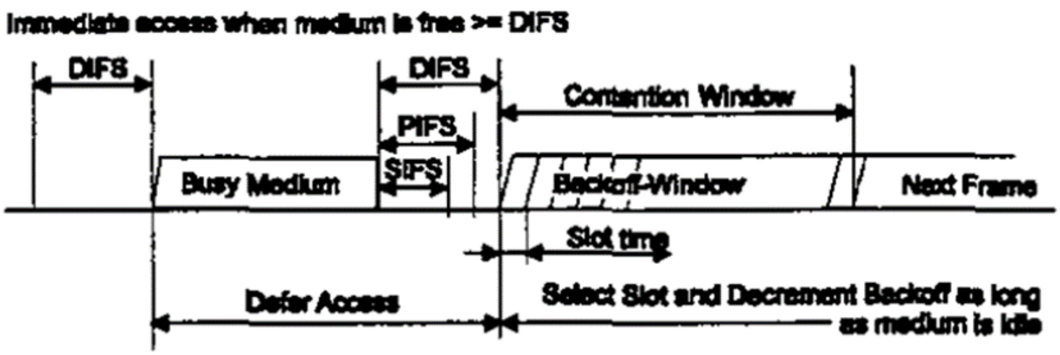


Figure 2: Legacy DCF operation

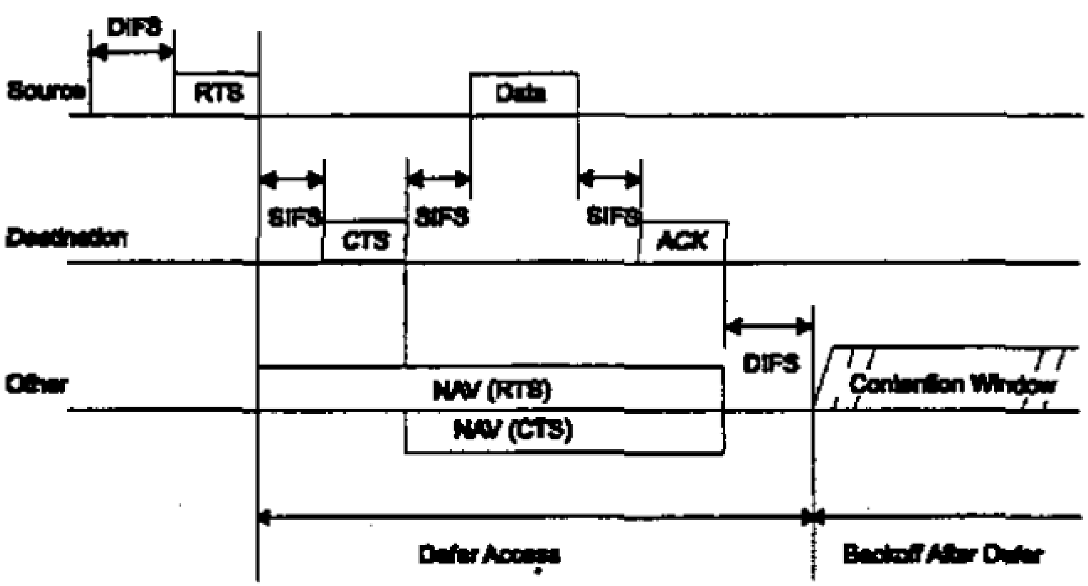


Figure 3: RTS/CTS and NAV settings

The new 802.1 le EDCF medium access scheme is governed by a distributed mechanism very similar to legacy 802.11 DCF. Service Differentiation is achieved through the introduction of Traffic Categories (TCs). Each TC has a different transmission queue and each transmission queue has a different inter6ame space (Arbitrary Inter Frame Space AIFS[TC]), a different set of contention window limits

(CWd[TC] and CW[RC]), and a different persistent factor (PF[TC]). Next section illustrates details about EDCA and the service differentiation accomplished by using different AIFS values.

The mostly used WLAN standard IEEE 802.11n protocol boosts the data rate up to 600 Mbps. While the IEEE 802.11ac standard aims to provides support for Very High Throughput (VHT) with PHY data rate up to 6 Gbps . The real throughput is less than the physical throughput owing to the overheads of the Medium Access Control (MAC) sublayer. Since, the shared channel has to remain idle for multiple slot times while contending stations carryout their time domain back-off. The proportion of such channel wastage is huge, which leads to significantly decreased MAC sub-layer efficiency. To send 1500-byte data packet in a 300 Mbps network, only 40 micro seconds time is necessary. But the combined overhead of DIFS, Contention Window and ACK result in another 120 micro seconds. Thus, in this scenario, MAC layer efficiency is only 25% Thus the idle time on back-off is at least 72s while the minimum CW size is 16 slot time. When multiple stations simultaneously back off in time domain to win the contention, the shared channel remains idle leading to underutilization. For example, only 40 micro seconds time is necessary to send a 1500-byte data packet in a 300 Mbps network. But the combined overhead of DIFS and Contention Window result2 in another 120 micro seconds. Thus, in this scenario, MAC layer efficiency is only 25%.

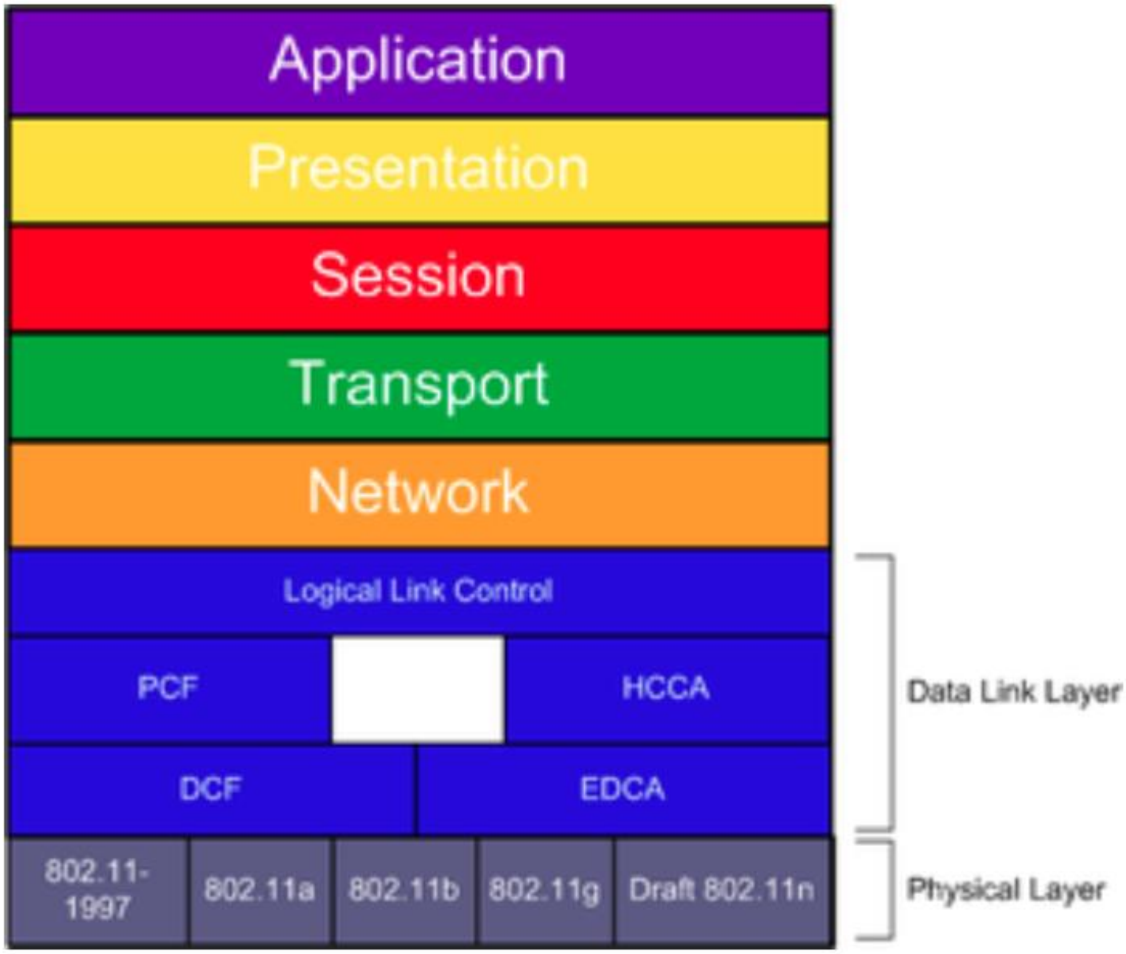


Figure 4: 7-layer OSI model

Standard EDCA Background:

EDCA provides a mechanism whereby traffic can be prioritized but it remains a contention based system and therefore it cannot guarantee a give QoS. In view of this it is still possible that transmitters with data of a lower importance could still pre-empt data from another transmitter with data of a higher importance.

When using EDCA, a new class of interframe space called an Arbitration Inter Frame Space (AIFS) has been introduced. This is chosen such that the higher the priority the message, the shorter the AIFS and associated with this there is also a shorter contention window. The transmitter then gains access to the channel in the normal way, but in view of the shorter AIFS and shorter contention window, this means that the higher the chance of it gaining access to the channel. Although, statistically a higher priority message will usually gain the channel, this will not always be the case.

HCCA

The HCCA adopts a different technique, using a polling mechanism. Accordingly, it can provide guarantees about the level of service it can provide, and thereby providing a true Quality of Service level. Using this the transmitter is able to gain access to a radio channel for a given number of packets, and only after these have been sent is the channel released.

The control station which is normally the Access Point is known as the Hybrid Coordinator (HC). It takes control of the channel. Although it has an IFS, it has what is termed a Point Coordination IFS. As this is shorter than the DIFS mentioned earlier, it will always gain control of the channel. Once it has taken control it polls all the stations or transmitters in the network. To do this it broadcasts as particular frame indicating the start of polling, and it will poll each station in turn to determine the highest priority. It will then enable the transmitter with the highest priority data to transmit, although it will result in longer delays for traffic that has a lower priority. (Wu, IEEE 2006)

In 802.11e EDCA, service differentiation is provided by assigning different contention parameters to different AC. A QoS station can support at most eight user priorities, which are mapped into four ACs. Each AC contends channel access with different AIFS and CW setting. Compared with DCF where DIFS is used as the common IFS for a station to access the channel, EDCF uses different AIFS for each AC to achieve the access differentiation, where the AIFS for a given AC is defined as

$$AIFS[AC] = AIFSN[AC] \times \delta + SIFS$$

The AIFSN denotes the number to differentiate the AIFS for each AC, and δ is the time interval of a slot for 802.11 standard, which is determined according to the physical medium used. Table 1 shows the default parameter settings defined for different ACs in 802.11e draft standard [2], where AC1 for voice is assigned the highest priority while AC4 for background is given the lowest priority.

Table 1: Default EDCA Parameter Set

AC	CWmin	CWmax	AIFSN	Max TXOP
AC_VO(Voice)	7	15	2	1.504ms
AC_VI(Video)	15	31	2	3.008ms
AC_BE (Best Effort)	31	1023	3	0
AC_BK(Background)	31	1023	7	0
Legacy DCF	15	1023	2	0

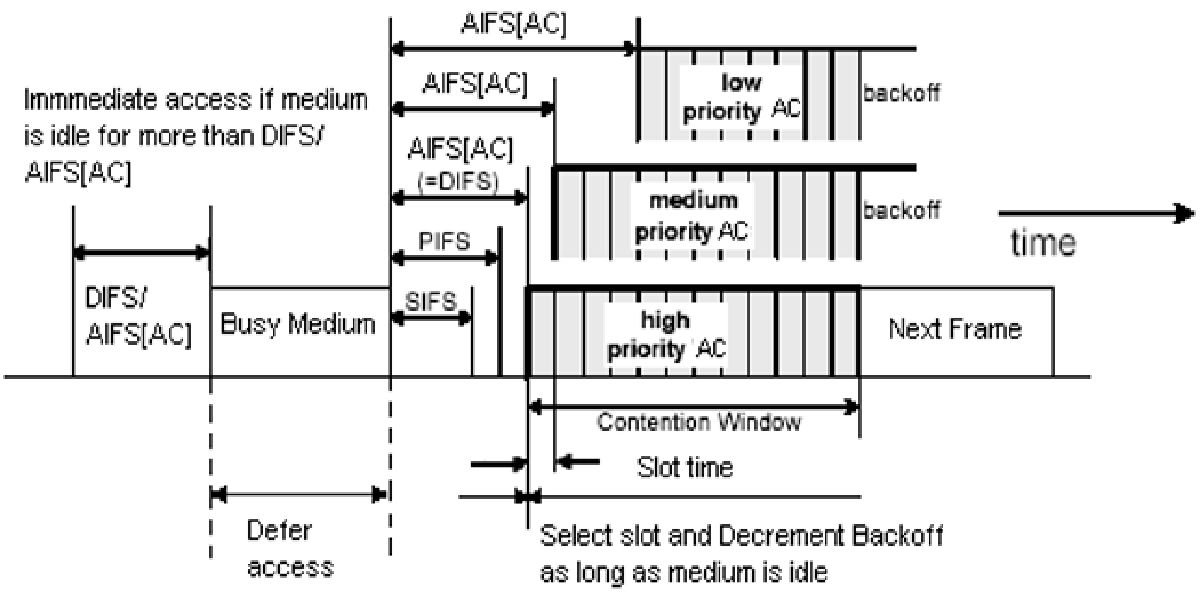


Figure 5 : Channel access in EDCA

To understand the service differentiation introduced by AIFS and CW, we use an example shown in Fig. 1, where there are two stations with packets in AC1 and AC4, respectively. The difference of AIFSN is 5, so the AC1 in STA1 will decrease its backoff counter 5 slots earlier than

AC4 in STA2. In addition, the backoff counter of high priority AC may count to zero in this interval and transmit the packet, which results in channel busy due to high priority packet transmission and resynchronization after that. Therefore, the backoff counter of low priority AC will be decreased much slower than that of the high priority AC. An interesting observation from this example is that, since the low priority AC cannot access the channel in the interval introduced by AIFS difference, different AC experiences different channel busy probability, which makes AC with high priority beneficial. Most of the modeling [6,7] for 802.11e EDCA do not take this effect into account except that the novel notation of contention zone in.

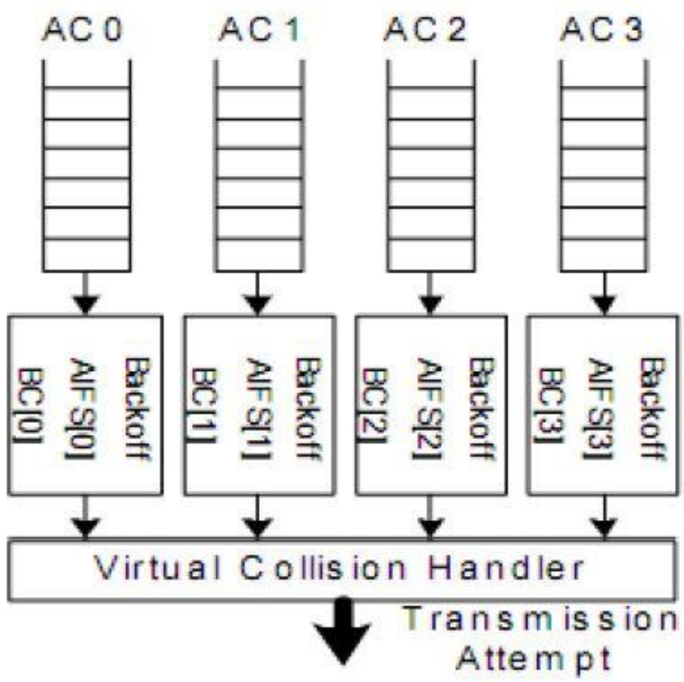


Figure 6: Station with multiple priority queues

In a single QoS station supporting EDCA, each AC is implemented as a separate queue, as shown in Fig. 2. Each queue behaves like a virtual station and contends for the channel access independently. When a collision occurs among different queues of the same station, i.e., two backoff counters of the queues decrease to zero simultaneously, the highest priority queue always wins the contention, and the lower priority queues act as if a collision occurred.

Problem Statement:

Channel access mechanism is randomized. All stations and their different access category choos random backoff value for channel access. They do not know which station is the winner or is there any probability of choosing same different backoff value. So, this randomize system is the main problem.

Different access categories may collide with each other. Because of randomize backoff in standard EDCA, there is lots of situation where two or more access categories between same and different station will collide.

As a result, there are lots of idle time. There is normally lots of idle time when all the stations wait for their backoff time. This waiting time increases exponentially when collision occurs. So, lots of idle time and channel wastage.

Also after establishing EDCA, above all the reason Probability of collision is still high.

Related Work:

Co-ordination based Scheme:

The coordination-based schemes utilize a central coordination for resource allocation. Central coordinator fixed the schedule.
A novel collision-free medium access control (MAC) scheme supporting multimedia applications is proposed for wireless mesh backbone. (Wang, 2009)

In (Panigrahi, 2009) , we consider the FRACTEL architecture for long-distance mesh networks. We propose a novel angular interference model, which is not only practical, but also makes the problem of TDMA scheduling tractable.

Slot-assignment scheme:

1. Winning the Lottery: Learning Perfect Coordination with Minimal Feedback (William Zame, 2013), ***EEE Journal of Selected Topics in Signal Processing* (2013) Globecom 2013 - Wireless Communications Symposium**

   PC protocols rely heavily on learning, exploiting the possibility to use both actions and silence as messages and the ability of stations to learn from their own histories while simultaneously enabling the learning of other stations.

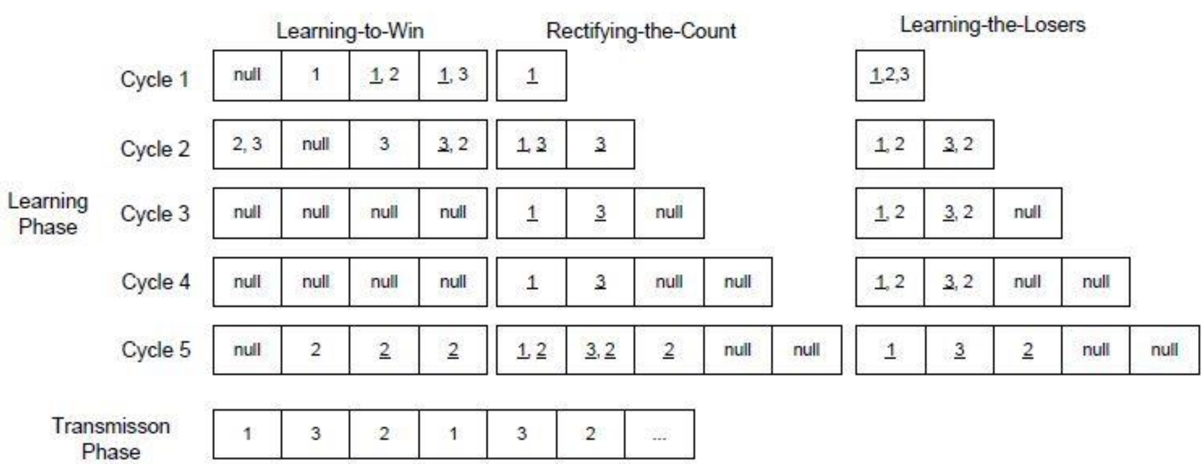


Figure 7: Illustration of PC protocol when N is known. (N = 3; K =4; Nmax = 4)

2. A Beacon-Based Collision-Free Channel Access Scheme for IEEE 802.11 WLANs (Tuysuz, 2014), ***Wireless personal communications* (2014)**
   The proposed scheme makes use of beacon frames sent periodically by access point, lets stations enter the collision-free state and reduces the number of idle slots regardless of the number of stations and their traffic load (saturated or unsaturated) on the medium.

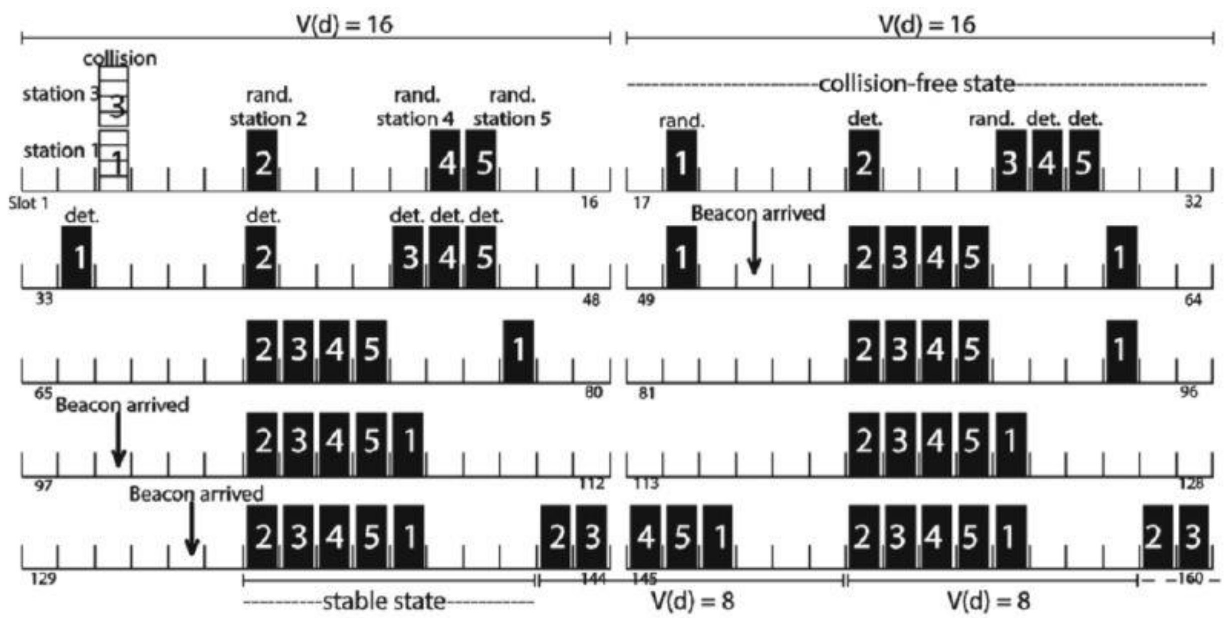


Figure 8: BCCA deterministic backoff selection procedure

3. E-MAC: An evolutionary solution for collision avoidance in wireless ad hoc networks (Zhao, 2016), **Journal of Network and Computer Applications (2016)**
   Proposes a simple collision-avoidance MAC (E-MAC) for distributed wireless networks that can iteratively achieve collision-free access. In E-MAC, each transmitter will adjust its next transmission time according to which part of its packets suffering from the collision. And the iteration of this adjustment will quickly lead group of nodes converging to a collision-free network. E-MAC does not require any central coordination or global time synchronization. It is scalable to new entrants to the network and variable packet lengths.

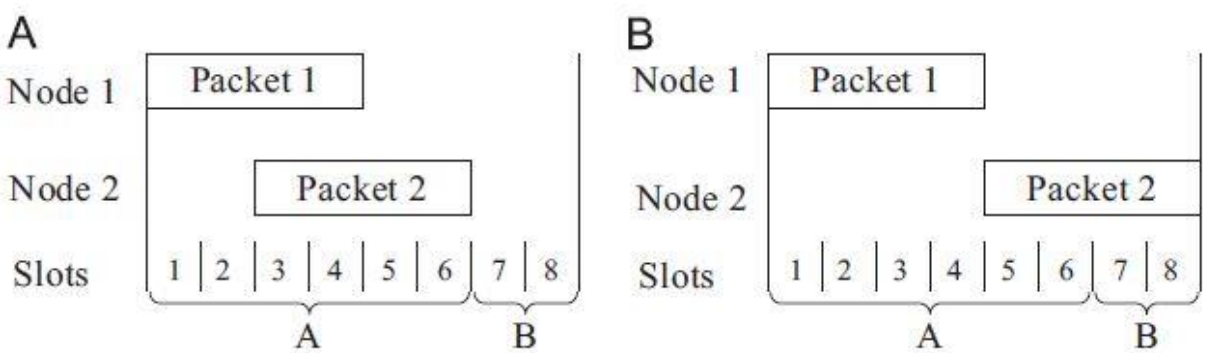


Figure 9: (a)the collision scenario and (b)a proper solution

Multi-frequency assisted schemes:

1. Frequency-Domain Backoff Mechanism for OFDM-Based Wireless LANs (Alvi, 2016), ***Arabian Journal for Science and Engineering 41.12*** **(2016)**
   FD-Backoff strategy works in Handshaking manners. Here each SC is assigned with an integer number which represents the backoff value. Every node transmits RTS through randomly chosen SC. In return every nontransmitter node (receiver) listens on the channel bandwidth and sends CTS to the winner. Transmitters advertise their SCN. This RTS/CTS mode sometimes may occur additional overhead.

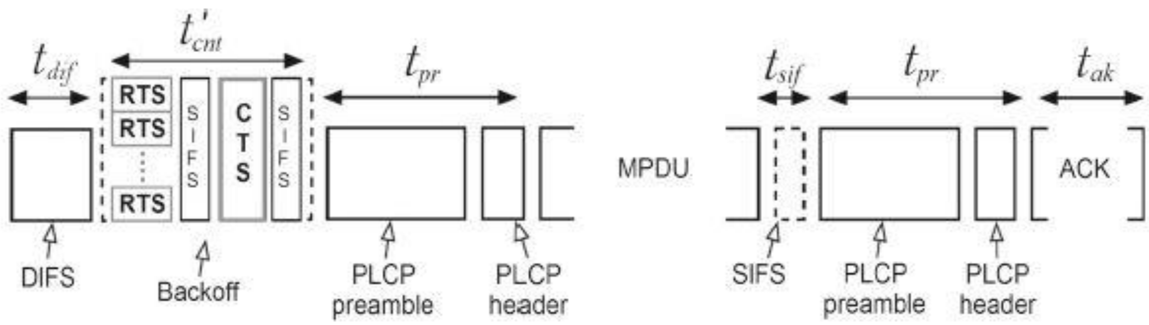


Figure 10: Successfully transmitted packet timing diagram using proposed scheme

2. Fine-grained channel access in wireless LAN (LAN, 2010), ***ACM SIGCOMM Computer Communication Review*** **(2010)**
   FICA divides wideband channel into a set of orthogonal subchannels using OFDM. Communication occurs individually in each subchannel. Initially all nodes will transmit M-RTS signal simultaneously. These signals are resolved at the AP, and the AP will broadcast the contention results in a corresponding M-CTS OFDM signaling symbol. Then, only the nodes assigned subchannels will use them for data transmissions. Collusion still may occur if two nodes select same sub carrier.

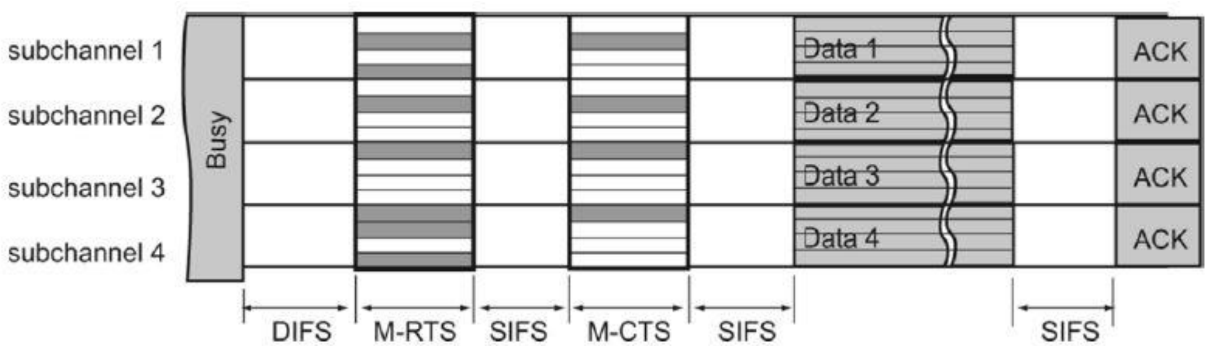


Figure 11: FICA uplink media access with four subchannels per channel

3. No time to countdown: Migrating backoff to the frequency domain (Sen, 2011), ***Arabian Journal for Science and Engineering*** **(2016)**
   Proposed Back2F strategy assumes, each node has two antennas. Each node transmits a symbol on a subcarrier according to its backoff time and also listen to the other's transmissions, thus determines the winner having lowest backoff time. Back2F also copes with
   - Collisions by introducing a second round of subcarrier based contention
   - Multiple Collision Domains, by allowing a losing node to transmit after DIFS
   - Misdetection due to Fading. But not defined clearly

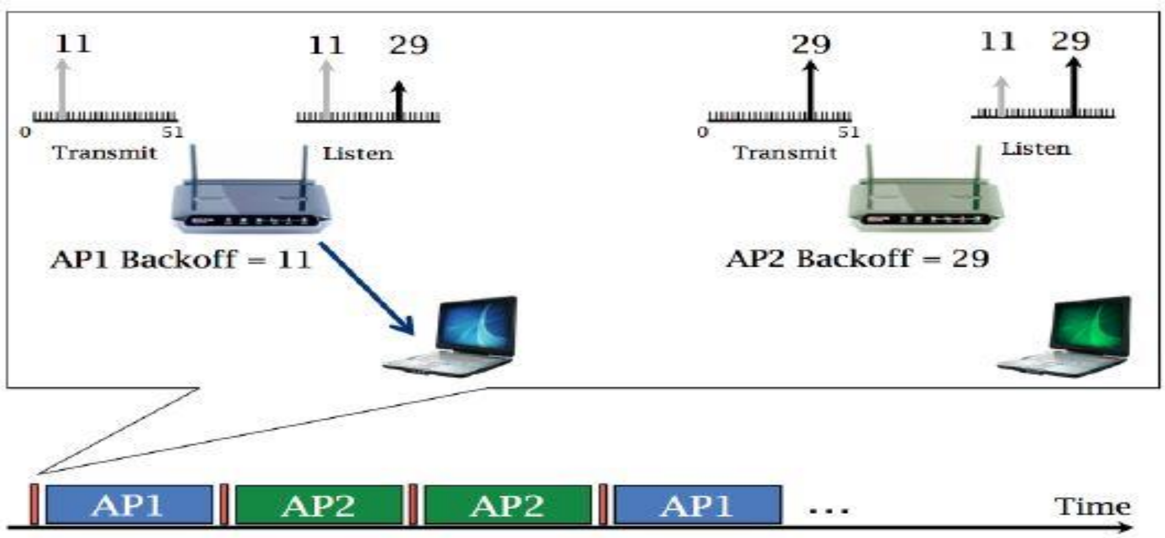


Figure 12: A close up view of the first backoff. AP1 picks/activates subcarrier 11 and AP2 chooses 29. They learn of other backoff values through subcarriers. AP1 with smaller backoff transmits whereas AP2 defers.

Approaches for improving QoS:

1. Improving the QoS performance of EDCF in IEEE 802.11 e wireless LANs (Wong, 2003), ***2003 IEEE Pacific Rim Conference***
   Real-time packets are obsolete if they are not received by recipients within their lifetime. Packets with queuing delay longer than the lifetime will eventually be discarded by their applications and should not contend for the medium. So. To make more efficient, Age-Dependent Backoff (ADB) is introduced where packets with Age > LT are discarded before attempting transmission to save bandwidth and to prevent causing additional delay to other packets.

2. Adaptive multi-polling scheduler for QoS support of video transmission in IEEE 802.11 e WLANs (Al-Maqri, 2016), ***Telecommunication systems*** **2016**
   Mainly focusing on prerecorded video, this paper proposed scheduler is powered by integrating multi-polling scheme. Here HC shall have collected information about the next frame size of all admitted TSs in the polling list. Accordingly, the HC compose one multipolling frame to be broadcast to all QSTAs and determine efficient TXOP.

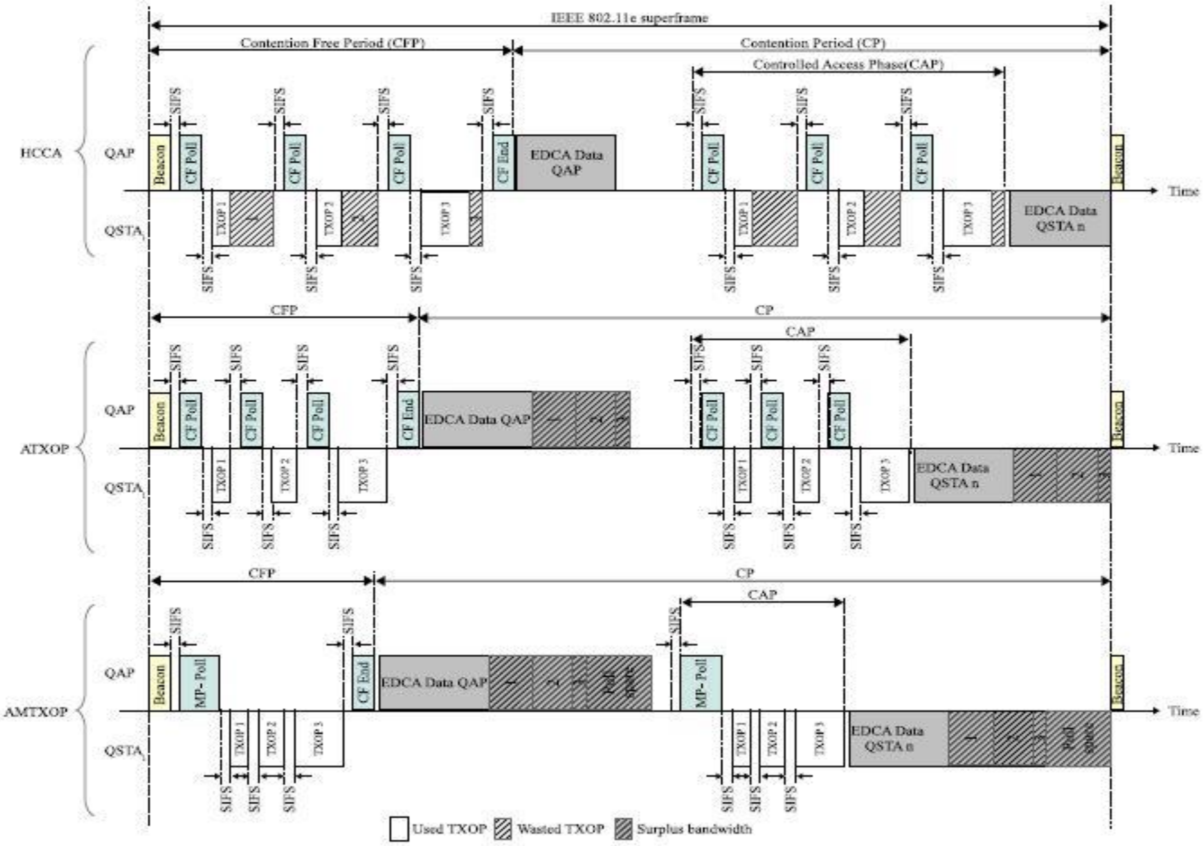


Figure 13: Dynamix TXOP assignment algorithm

Limitations of above approaches:

1. Coordination-based schemes is a single point of failure. It also requires costly infrastructure.
2. In multi-frequency assisted or OFDMA schemes, it requires extra infrastructure, like dual antenna in all stations. This also limits their scalability.
3. In slot assignment schemes, Global Synchronization needed. Extra Learning and set up phase is needed for steady scheduling. This learning causes additional time consumption. These processes are also vulnerable to slot drifts.
4. Though QoS approaches have significant impact on improving quality of service but these approaches are based on central coordination and polling based. But in EDCA we need decentralized approaches.

Proposed solution:

Modified Deterministic back-off:

The basic idea of deterministic back-off is that if two stations successfully transmit in two different slots they will not collide with each other. They will periodically transmit in the same relative position. (Luis-Barcelo, TON2017)

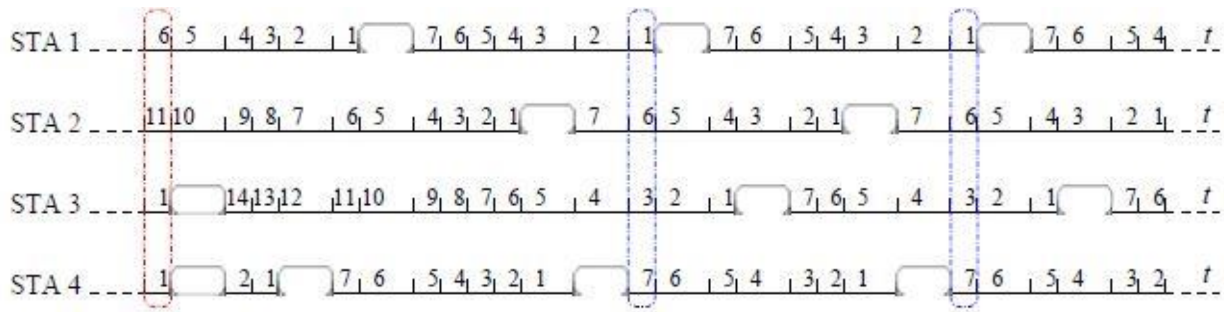


Figure 14: An example of the deterministic backoff

In our solution we have modified this deterministic approach and add new features to make the channel access more efficient and reliable. Main features of our proposed solution are given below:

Modified Deterministic back-off:

- Different access categories will use deterministic back-off value after successful transmission.

- The range for the back-off value for different categories will be different.
- A station with a deterministic back-off value will never collide with the same genre.

- As an example below, all the station who has succeed to transmit their packet join in with deterministic value of 5. And continue with that backoff.

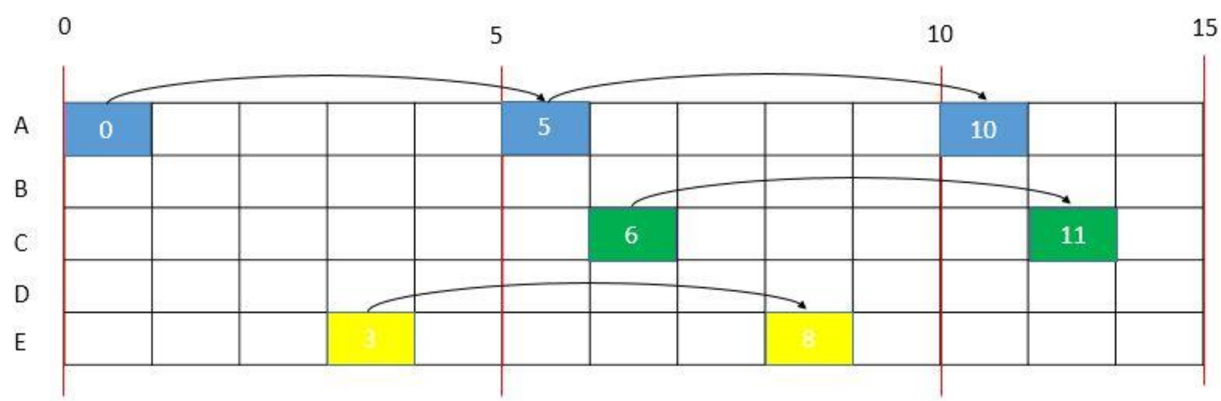


Figure 15: Stations using deterministic backoff

Use of multiplicative approach:

- In the case of collision, the increase of the deterministic back-off value will be multiplicative to the minimum value chosen from the first success.

- So, in non-congested scenario two nodes from different categories with same genre will not collide.

- Successful periodical transmission is achieved using the proposed back-off process.
- As an example, we have shown two stations (A and B) with two access categories. Initially Low priority has deterministic value of 6 and High priority has deterministic value of 6. (Fig:15)

Retry Counter:

- In a non-congested scenario, deterministic node can collide with the random ones

- Unnecessary jump to a greater deterministic back-off value due to collision

- The collided node will wait for a sudden limit and use the same deterministic back-off value

- After reaching the limit, the deterministic back-off value will be increased using the proposed multiplicative back-off process.

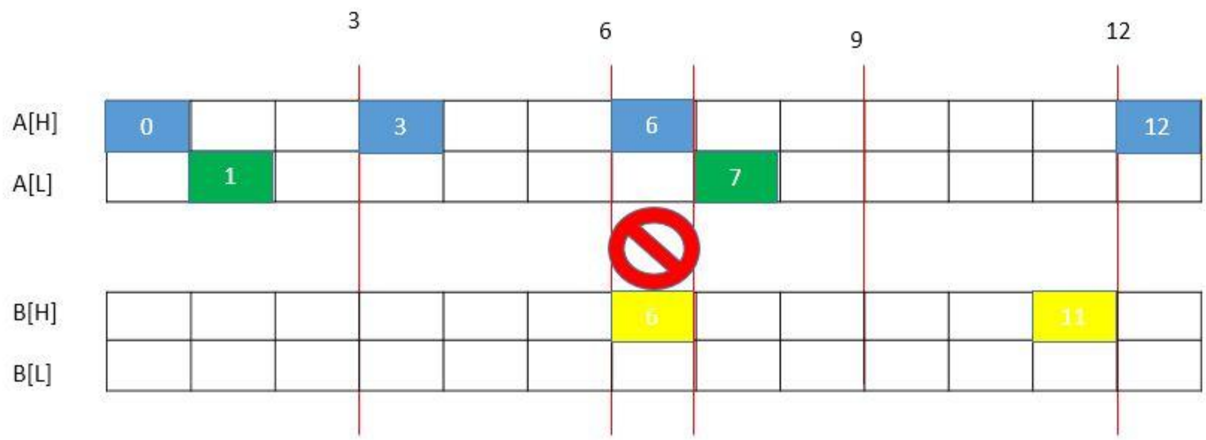


Figure 16: Different stages of multiplicitive back-off

Faster convergence to a collision-free schedule:

- A learning phase from the beginning of the active period.
- Try to identify the number of nodes in the collision domain using MAC layer packet format
- In a congested scenario, during collision jump to a suitable back-off value for avoiding collision using the learning phase.

Simulation and Performance Evaluation:

Simulation Model:

Our proposed method has been implemented in the well-known network simulator (*ns-3*) version (3.35). NS-3 provides the access control and access mode of IEEE 802.11e functions. The standard EDCA functions has already provided in ns3.

For evaluating the performance of our proposed solution against the standard protocol of “HCCA/EDCA”, we have taken 10 stations and simulate them on an ad-hoc network consisting of two level of priority (High Priority AIFS[H] and Low Priority AIFS[L]). We assume that no hidden stations are present in the independent BSS. Stations start their transmission after 20 (s) from the start of the simulation time and last until the simulation end. Wireless channel assumed to be an error-free. Simulation parameters are summarized in Table 2.

Parameters	Value
Channel rate	11Mbps
Slot time	20µs
SIFS	10µs
DIFS(DCF)	50µs
AIFS[H]	50µs
AIFS[L]	110µs
Deterministic Backoff Value	7n (n=1,2,3…)
[CWmin, CWmax] (DCF)	[31, 1023]
[CWmin, CWmax] (High)	[7,35]
[CWmin, CWmax] (Low)	[14,245]

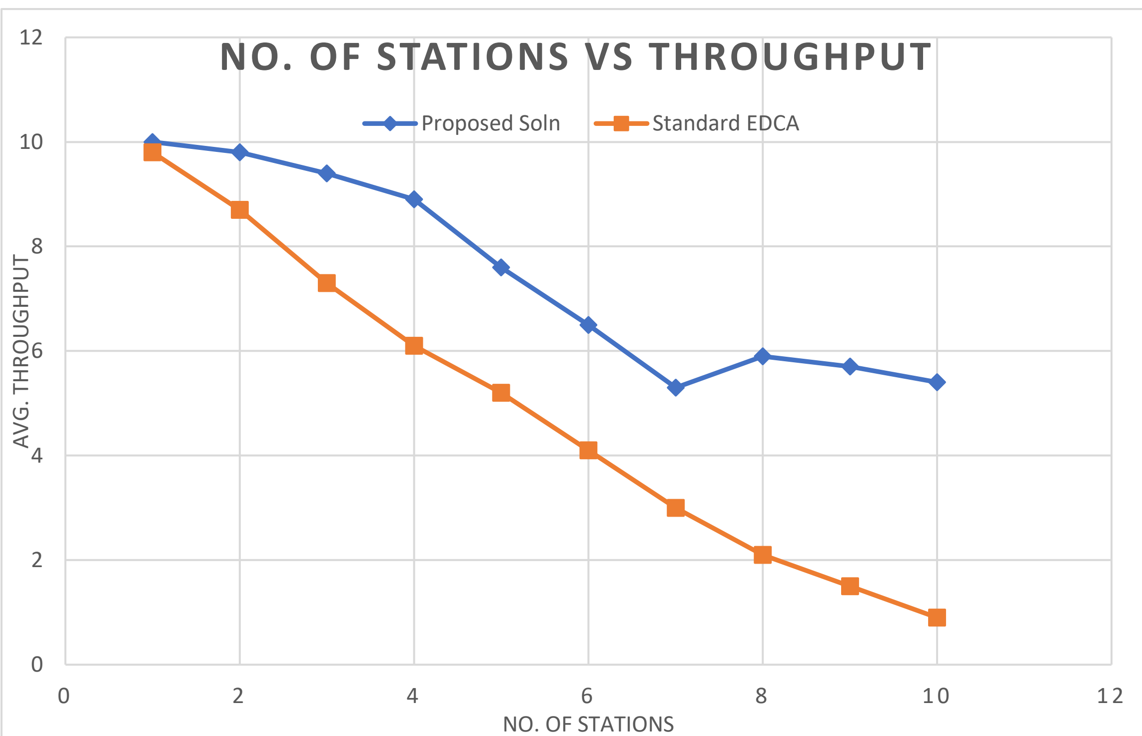
Table 2: Simulation Parameters

Simulation result is compared between our proposed scheme and standard EDCA based on Effect on Throughput, Effect on Collision Probability and End to End Delay. All graphs are made in number of stations vs evaluation parameter.

Performance Evaluation:

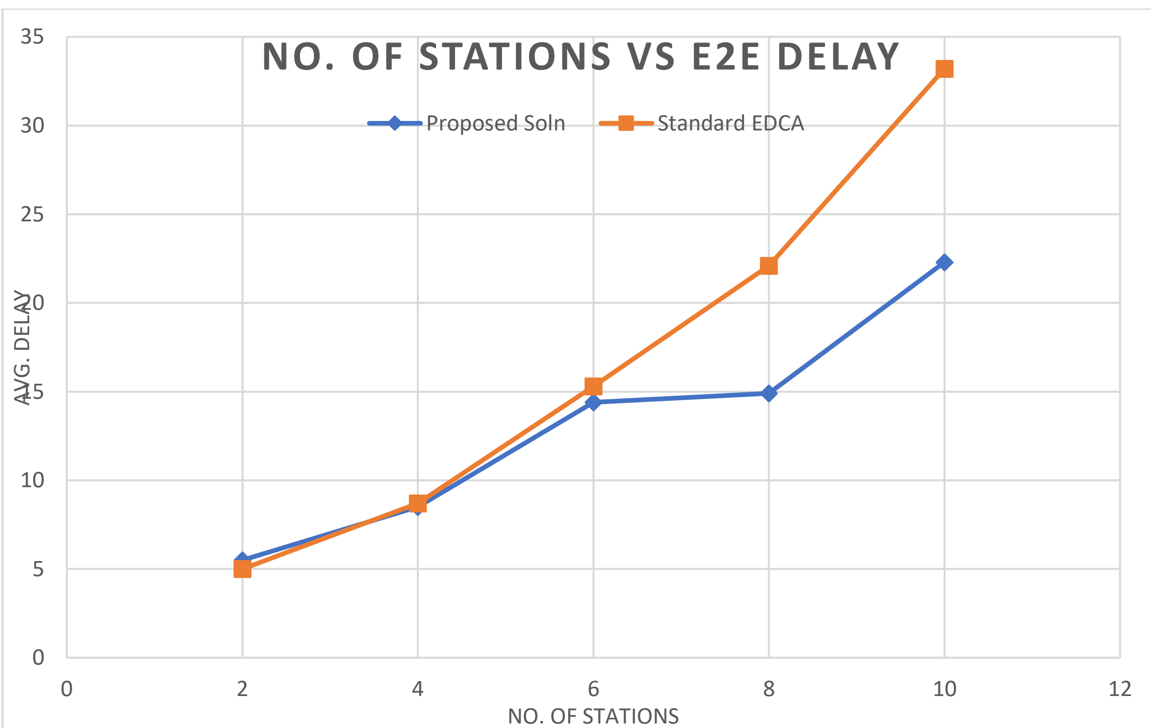
Effect on Throughput:

Significant result came out from simulation. In standard EDCA average throughput decreases exponentially with the number of stations. On the other hand, in first backoff value throughput is decreases and after the congestion stage is reached and backoff value is multiplied then throughput again changes from new stage. The overall throughput is better than standard edca.



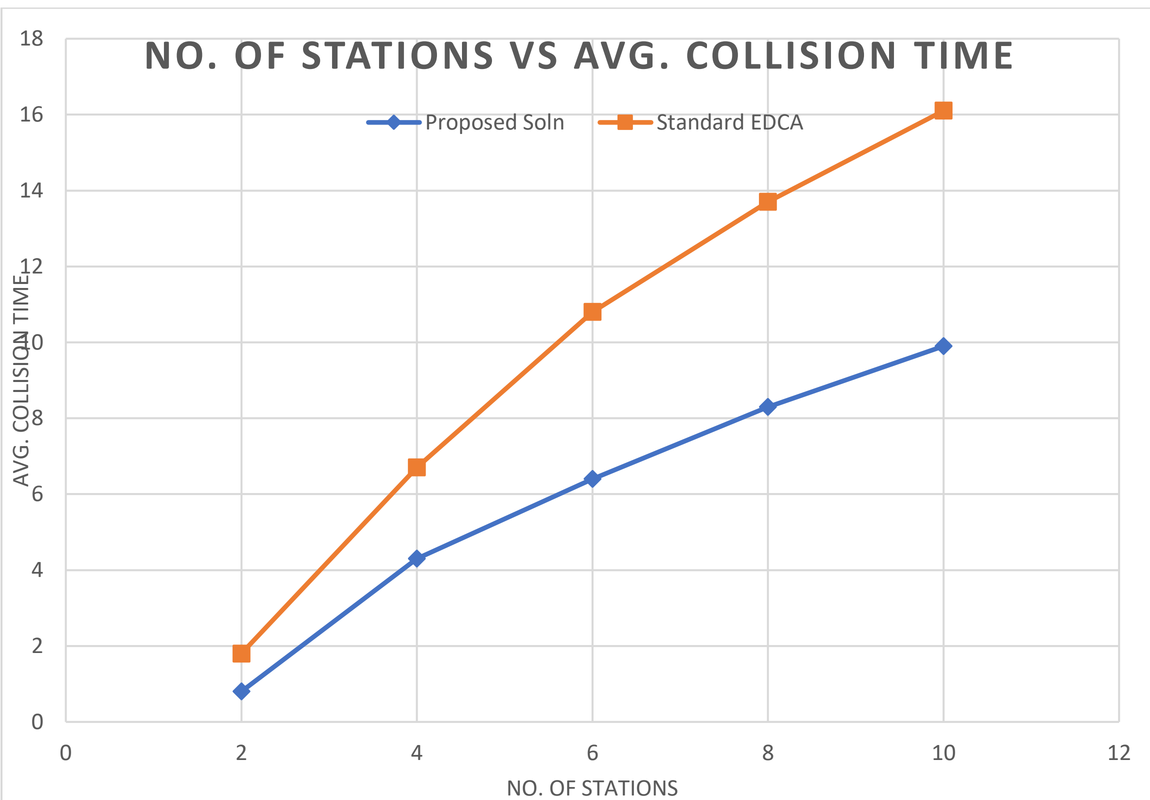
Effect on End to End Delay:

In standard EDCA average end to end delay increases exponentially with the number of stations. As the collision get high with the number of stations thus causing exponential backoff value is creating more delay. On the other hand, in first backoff value delay increases but overall end to end delay is better than standard edca because of multiplicative backoff approach.



Effect on collision probability:

Collision between different access categories is high asper number of stations. Because of randomize backoff approach in standard EDCA probability of collision is increased with the proportion of stations. Instead of randomize approach, our backoff scheme gives much less collusion between stations. Different backoff values between access categories reduce collision between them. On the other two stations using deterministic backoff do not collide until congestion occurs.



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