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A Study on Fair Medium Allocation for Intraclass Fairness Enhancement in IEEE 802.11e

조선대학교 대학원
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요약

IEEE 802.11e 에서 Intraclass fairness 공정성 향상을 위한 공정한 채널 할당에 관한 연구

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무선랜 환경에서 공정한 자원 할당과 관련된 연구들은 채널 자원이 중앙 컨트롤러에 의해 주기적으로 할당되는 중앙 집중형 네트워크에서 주로 연구되고 있다. 선행 연구들에서는 다양한 사용자들에게 채널의 자원을 할당하고 제어하는 것이 기 측정된 처리량과 트래픽의 패킷 손실률(PLR) 등을 기반으로 하고 있다. 하지만 이러한 공평한 액세스 메커니즘을 비동기적 분산형 인프라리스 네트워크에서 구현하는 것이 쉽지만은 않다. 유선과 비교했을 때 무선 매체가 훨씬 더 예측하기 어려우며 에러 또한 발생하기 쉽다. 따라서, Fairness 의 문제에 있어 무선 네트워크에서의 실시간 처리에 대한 연구의 중요성이 점점 더 높아지고 있다.

본 논문에서 우리는 IEEE 802.11e 에서 여러 종류의 매체 할당 기술에 대해서 연구했으며, 또한 인프라가 없는 무선 네트워크 환경에서 Intra-class 기반에서의 공정한 자원 할당을 수행할 수 있는 새로운 프로토콜인 Intra-class Fair Medium Access (IFMA) 를 제안하였다. 본 논문에서 제안하는 IFMA 메커니즘은 일반적인 IEEE 802.11e MAC 을 기반으로 하여 설계된다. 제안하는 방식의 기본적인 개념은 MAC contention parameter 들인 Arbitration Inter-frame Space Number(AIFSN)와 Contention Window(CW)를 사용자의 서비스 상태에 따라

조절하는 것이다. 기본적으로 패킷 손실률(PLR)이 큰 사용자들이 매체에 액세스하기 위한 우선순위를 더 높게 설정되는 방식으로 해당 사용자의 상대적 빈곤을 보상한다. 제안하는 IFMA 메커니즘은 노드들이 채널을 액세스하는 확률을 실시간으로 사용자 별로 맵핑함으로써 같은 종류의 트래픽 간의 서비스 관점에서의 공정성을 제공한다. 결과적으로 IFMA 는 실시간 트래픽에 대해 PLR 이 높은 사용자들의 채널 접근 확률을 높이고 PLR 이 낮은 사용자들의 채널 접근 확률을 상대적으로 줄임으로써 기존 Interclass 의 차별성을 손상시키지 않으면서 Intraclass fairness 를 증가시킬 수 있게 된다.

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Acronyms

AC	Access Category
ACK	Acknowledgement
AEDCA	Adaptive Enhanced Distributed Channel Access
AIFS	Arbitrary Inter-frame Space
AIFSN	Arbitrary Inter-frame Space Number
BE	Best Effort Traffic
BK	Background Traffic
CA	Collision Avoidance
CFP	Contention Free Period
CP	Contention Period
CSMA	Carrier Sense Multiple Access
CTS	Clear to Send
CW	Contention Window
DCF	Distributed Coordination Function
DE-AEDCA	Differentiation Enhanced AEDCA
DIFS	Distributed Inter-frame Space
EDCA	Enhanced Distributed Channel Access
FR	Frozen Rate
IEEE	Institute of Electrical and Electronics Engineers
IFMA	Intra-class Fair Medium Access
MAC	Medium Access Control
MACD	Media Access Delay
NPLR	Normalized Packet Loss Ratio
PC	Point Coordinator
PCF	Point Coordination Function
PDF	Probability Distribution Function
PIFS	Point Inter-frame Space
PLR	Packet Loss Ratio

QD	Queuing Delay
QoS	Quality of Service
QST	QoS Enhanced Station
RTS	Request to Send
SD	Standard Deviation
SD-AEDCA	Service Differentiation AEDCA
SIFS	Short Inter-frame Space
STA	Station
TXOP	Transmission Opportunity
VI	Video Traffic
VO	Voice Traffic
WLAN	Wireless Local Area Network
WT	Waiting Time

I. Introduction

A. Research Overview

Due to frequent improvements in the IEEE 802.11 standard, Wireless Local Area Network (WLAN) has positioned itself as the most prevailing technology for the wireless networking. At present there is a significant increase in the use of multimedia applications, such as video streaming, wireless gaming, etc. Along with many emerging applications and services over WLANs, the demands for faster and higher capacity WLANs have been growing rapidly. Recently, the needs for real-time services, such as Voice over IP (VoIP) and teleconferencing via WLANs have been increasing significantly. To cope up with the developments in real time services and to satisfy their ever increasing demands is a big challenge in itself.

Multimedia applications require Quality of Service (QoS) support such as guaranteed throughput, bounded delay and jitter. As a step towards meeting multimedia application requirements in WLAN networks, the 802.11 has pursued a standard called IEEE 802.11e, which provides service differentiation at the MAC layer. Enhanced Distributed Channel Access (EDCA) mechanism of IEEE 802.11e is used as the fundamental access mechanism for the MAC layer to provide QoS. Although, EDCA provides the service differentiation, recent studies have shown that under heavy traffic load, i.e. when number of QoS enhanced stations (QSTs) in the network increases, the resulting contention issues increase highly, leading to performance degradation as well as fairness issues. It can even lead to high lack of bandwidth and state of starvation for some nodes. Therefore to get the full benefits of EDCA, it is very important to make sure that traffic is properly regulated with fair access among all nodes. Moreover, EDCA is a priority-based service which allows differentiated service for flows of different priorities but there is no provision for fairness among the users of the same traffic priority. IEEE 802.11 is highly criticized for such fairness issues among users. Especially the edge users suffer more from this lack of inbuilt provision.

B. Research Objective

Let us consider a scenario where there are K flows of real time traffic. Let us further assume that all the flows are experiencing different PLR due to both contention and collision in the system. For such scenario where different flows are experiencing heterogeneous PLR, it would be much better if the flow experiencing higher PLR could be prioritized to access the channel earlier than the flows having lower PLR without disturbing the original Access Category (AC) prioritization. Such flow prioritization results in intra-AC packet loss fair access which is hereafter termed as Intraclass Fairness in this paper.

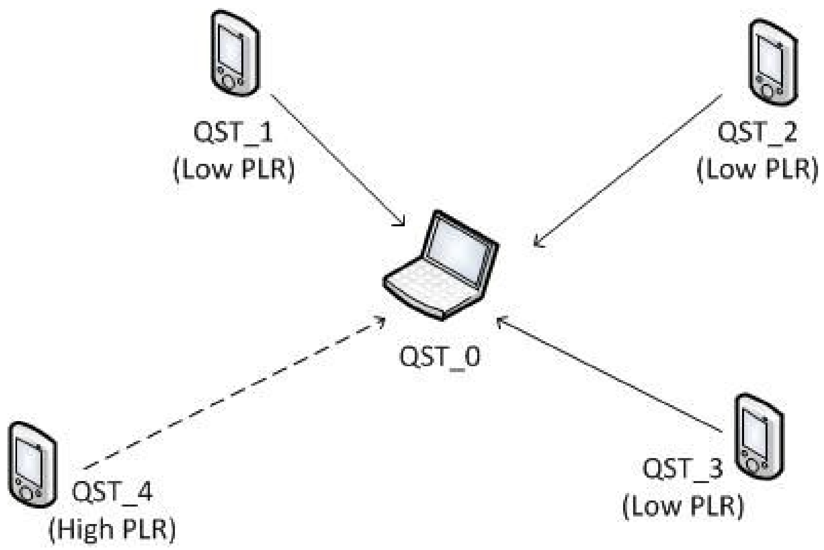


Figure 1- 1: Wireless network scenario where multiple stations are sending real time signals to a station QST_0. Traffic from one of the station, QST_4 is experiencing higher PLR than other QSTs.

In Fig. 1-1, we consider four different QSTs trying to send video signals to a base station, i.e. QST_0. We further consider that due to some reason QST_4 is performing worse than other QSTs and it is not getting enough opportunity to access the medium. Since all of the four QSTs are sending signals of the same traffic priority, we want to give more priority to QST_4 to access the medium so that all the QSTs would perform equally. Motivated with the aforementioned example, in this paper, we present a scheme to prioritize the flows experiencing higher PLR (intra-AC differentiation) without disturbing the original inter-AC differentiation. The proposed intra-AC differentiation framework is developed by probabilistically mapping perceived PLR to the Arbitrary Inter-Frame Space (AIFS) time; higher the PLR is, lower will be the AIFS time and vice versa. The details are presented in section II.

C. Research Layout

The research layout we followed was in accordance with the objective of the carried research. We structured our works in three parts. First part deals with the introduction of range of values for contention parameters instead of single static values as in legacy schemes. We carefully studied the operation of wireless medium access mechanisms and decided upon the most appropriate range for various traffic categories. The second part deals with performance characterization of the users in the network. We identified the most effective metrics for analyzing the performance and came up with a function to appropriately make use of the derived metrics. Finally the third part deals with the adaptation of the contention parameter values based on its current performance in the network.

D. Thesis Contribution

The characteristics parts of the carried research work are summarized under the title of the thesis contribution. They are as follows.

- IFMA, a new MAC protocol for intraclass fairness enhancement in IEEE 802.11e has been developed. We have derived this protocol based on current medium access protocol for service difference differentiation EDCA. EDCA consist of contention parameters whose main purpose is to provide interclass service differentiation among traffics of different access categories. In IFMA, we have modified the contention parameters and extended their significance to include intraclass fairness as well.
- In EDCA, traffics of the same AC will always use same values for contention parameters which means, it does not have any inbuilt provision for differentiation among traffics of the same AC. In IFMA, we have increased the range of possible values for contention parameters and we have implemented a functionality to increase the probability for the QSTs to select the most appropriate values for contention parameters based on its current performance. This would eventually lead to intraclass fairness for each users of the same AC without disturbing the original interclass service differentiation.

E. Thesis Organization

The organization of the rest of the thesis is as follows. Chapter 2 is devoted to brief overview of different medium access mechanisms in IEEE 802.11. We take a deeper look at one of the medium access mechanisms, EDCA in this section and also explain its significance and known issues related to it. Along with that we also present different enhancement approaches for EDCA. In chapter 3, the proposed new model IFMA is presented. We explain the enhancement modifications made in the model and also present the performance evaluation of this new model. The last chapter concludes the thesis with wrapping text for the summary of the carried research and possible future works.

II. Medium Access Mechanism in IEEE 802.11e

A. Introduction to Medium Access Mechanisms

In IEEE 802.11 based WLAN standard, there are mainly two type of medium access mechanisms, Distributed Coordination Function (DCF) and Point Coordination Function (PCF). Many variations and enhancements of these two coordination functions have been derived. In this section we will study few of them.

1. Distributed Coordination Function (DCF)

DCF is the fundamental mechanism to access the medium In the 802.11 protocol. It is a random access scheme, based on the carrier sense multiple access with collision avoidance (CSMA/CA) protocol. Retransmission of collided packets is managed according to binary exponential backoff rules. A station (STA) with a frame to transmit shall invoke the carrier-sense mechanism to determine whether the wireless medium is busy or idle. In the case of a busy medium, the STA shall defer transmission until the medium is idle without interruption for a period of time equal to a Distributed Interframe Space (DIFS). After this period, the STA shall generate a random backoff period for an additional deferral time before transmitting. The backoff period is slotted for efficiency reasons and is expressed in terms of an integer number of elementary backoff slots. Such a number, which is called the backoff counter, is decremented as long as the medium is sensed idle. Backoff counter is frozen when a transmission is detected on the channel, and reactivated when the medium is sensed idle again for more than a DIFS. The STA transmits when the backoff time reaches zero.

2. Point Coordination Function (PCF)

Point Coordination Function (PCF) is a centralized, polling-based access mechanism which requires the presence of a base station that acts as Point Coordinator (PC). If PCF is to be used, time is divided into superframes where each superframe consists of a contention period (CP) where DCF is used, and a contention-free period (CFP) where PCF is used. The CFP is started by a beacon frame sent by the base station, using the ordinary DCF access method. Therefore, the CFP may be shortened since the base station has to contend for the medium. During the CFP, the PC polls each station in its polling list (the high priority stations), when they are clear to access the medium. To ensure that no DCF stations are able to interrupt this mode of operation, the interframe space between PCF data frames (PIFS) is shorter than the usual IFS (DIFS). To prevent starvation of stations that are not allowed to send during the CFP, there must always be room for at least one maximum length frame to be sent during the contention period.

B. Enhanced Distributed Channel Access (EDCA) Mechanisms

The IEEE 802.11e EDCA is a QoS extension of IEEE 802.11 Distributed Coordination Function (DCF). The major enhancement to support QoS is that EDCA differentiates packets using different priorities and maps them to specific ACs which are buffered in separate queues at a station. Each AC within a station having its own EDCA parameters, contends for the channel independent of the others. Levels of services are provided through different assignments of the AC-specific EDCA parameters; AIFSN, CW, and Transmission Opportunity (TXOP) limits. EDCA is designed to provide prioritized QoS by enhancing the contention-based DCF. Each AC behaves as a single DCF contending entity with its own contention parameters as described above. The purpose of using different contention parameters for different queues is to give a low priority class a longer waiting time than a high-priority class, so that the high-priority class is likely to access the medium earlier than the low-priority class.

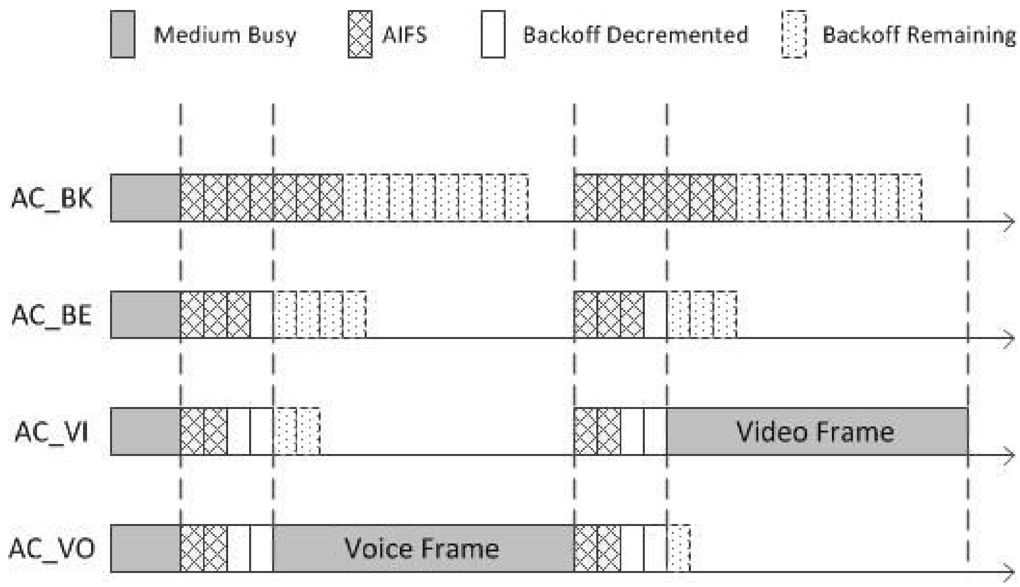


Figure 2- 1: AIFS and backoff time contend for channel access in EDCA.

If there is a packet ready for transmission in the MAC queue of an AC, the EDCA function must sense the channel to be idle for a complete AIFS before it can start the transmission. The AIFS of an AC is determined as follows.

$$AIFS = SIFS + AIFSN * Tslot \quad (2.1)$$

where AIFSN is the AC-specific AIFS number, SIFS is the length of the Short Interframe Space, and Tslot is the duration of a time slot. If the channel is idle when the first packet arrives at the AC queue, the packet can be directly transmitted as soon as the channel is sensed to be idle for AIFS. Otherwise, a backoff procedure is initiated following the completion of AIFS before the transmission of this packet. A uniformly distributed random integer, namely a backoff value, is selected from the range [0, CW]. The backoff counter is decremented at the slot boundary if the previous time slot is idle. If the channel is sensed busy at any slot time during AIFS or backoff, the backoff procedure is suspended at the current backoff value. The backoff procedure resumes as soon as the channel is sensed to be idle again. When the backoff counter reaches zero, the packet is transmitted in the following slot.

1. Contention Parameters and Their Significance

In EDCA, levels of services are provided through different assignments of the AC-specific contention parameters; AIFS, Minimum CW (CWmin), Maximum CW (CWmax) and Transmission Opportunity (TXOP). Each AC behaves as a single DCF contending entity with its own contention parameters as described above.

The higher priority ACs are assigned smaller AIFSN. Therefore, the higher priority ACs can either transmit or decrement their backoff counters while lower priority ACs are still waiting in AIFS. This results in higher priority ACs facing a lower average probability of collision and relatively faster progress through backoff slots. Moreover, in EDCA, the ACs with higher priority may select backoff values from a comparably smaller CW range. This approach prioritizes the access since a smaller CW value means a smaller backoff delay before the transmission.

Table 2- 1: Default values of the contention parameters for different ACs in EDCA

Access Category (AC)	AIFSN	CWmin	CWmax	TXOP
Voice (VO)	2	7	15	3.008 ms
Video (VI)	2	15	31	6.016 ms
Best-Effort (BE)	3	31	1023	0
Background (BK)	7	31	1023	0

The value of backoff timer is selected randomly from the range [0, CW] where CW is between CWmin and CWmax. The value of CW depends on the number of retransmissions the current packet has experienced. The initial value of CW is set to the AC-specific CWmin. If the transmitter cannot receive an Acknowledgment (ACK) packet from the receiver within a timeout interval, the transmission is labeled as unsuccessful and the packet is scheduled for retransmission. At each unsuccessful transmission, the value of CW is doubled until the AC-specific CWmax limit is reached. The value of CW is reset to the AC-specific CWmin if the transmission is successful, or the retry limit is reached in which case the packet is dropped.

After gaining the access to the medium, each AC may carry out multiple frame exchange sequences as long as the total access duration does not go over a TXOP limit. Within a TXOP, the transmissions are separated by SIFS. Multiple frame transmissions in a TXOP can reduce the overhead due to contention. An internal (virtual) collision within a station is handled by granting the access to the AC with the highest priority. The ACs with lower priority that suffer from a virtual collision run the collision procedure as if an outside collision has occurred.

2. Issues with EDCA

Although, EDCA provides the service differentiation, recent studies have shown that under heavy traffic load, i.e. when number of QoS enhanced stations (QSTs) in the network increases, the resulting contention issues increase highly, leading to performance degradation as well as fairness issues. Moreover, EDCA is a priority-based service which allows differentiated service for flows of different priorities but there is no provision for fairness among the users of the same traffic priority. IEEE 802.11 is highly criticized for such fairness issues among users. Especially the edge users suffer more from this lack of inbuilt provision.

III. IFMA: A New Model for Intraclass Fairness Enhancement

A. Introduction

Fair medium access is strongly desirable characteristics for the real time applications. Thus we present the proposed scheme in context of real time traffics. The proposed mechanism of IFMA provides differentiation among traffics of the same category by mapping the individual node's channel access probability directly to its observed real time performance. As a result IFMA makes the poorly performing nodes prone to the faster channel access thereby increasing the *Intraclass Fairness* without compromising the existing interclass differentiation. A point should be noted that this scheme does not focus on the fairness increment among the users, but instead it considers the fairness increment among flows from different users with the same traffic priority. Operation of IFMA is based on the selection of appropriate value for the contention parameters AIFSN and CW according to the current performance of the node.

B. Related Works

Many studies have been carried out to mitigate the fairness issues in EDCA function. Several methods have also been proposed to solve the contention issues mentioned above. Most of the proposed schemes deal with the adaptation of one of the priority parameters like AIFSN, CW or TXOP based on system performance.

In [4], Wang et al. have suggested a randomized AIFSN combined with adaptive selection of CW based on the drop rate of each node. The main goal of the scheme in [4] was to reduce intra-AC collisions and ultimately enhance the performance of EDCA network. Wang et al. have proposed a new scheme and referred it as Random Adaptive MAC Parameter Scheme (RAMPS). [4] defines RAMPS as an enhancement of the IEEE 802.11e EDCA that aims at minimizing the high collision rate observed in EDCA at high traffic loads. On average, an AC waits for a period which is equal to the backoff time plus the deferred time. The backoff time is based on selecting a random number from a range of values defined over the contention window size, whereas the deferred time is determined from the AIFS and is measured in timeslots. In RAMPS, random offset in CW is calculated by taking into consideration the per-AC drop rate at each station. The backoff time is selected randomly between $[0, (CW+1)^a]$ instead of [0, CW] where *a* is the per-AC drop rate. Here, if the drop rate is higher, the backoff window interval is also higher which leads to collision reduction for ACs with high drop rate. In addition to the contention window size based intra-AC differentiation scheme described above, RAMPS uses an AIFS-based scheme to further achieve intra-AC discrimination of the same traffic on different QSTAs. This scheme is used in support of the CW-based scheme to ensure that two ACs of the same priority are unlikely to choose the same backoff value. Some differentiation in terms of deferred time is achieved through the use of AIFS by allocating an interval of AIFSN values to each AC instead of a fixed single value that is used in EDCA. The range of AIFSN in each AC is defined. AIFSN(i) is greater than AIFSN(i+1), where AIFSN(i) is the value for a higher priority AC and AIFSN(i+1) is that of the lower priority AC. Whenever an AC enters a deferred period, it will select a random value from the AIFSN range. This value is then added as an offset to the previous value of AIFSN as in Eqn. (3.1). The resulting value is then used as the current AIFNS value that is used for calculating the AIFS as in Eqn. (2.1)

$$AIFSN_{new} = AIFSN_{old} + AIFSN_{offset} \text{ ,} \tag{3.1}$$

where $AIFSN_{old}$ is the previous AIFSN value used by the node and $AIFSN_{offset}$ is the offset value selected randomly between a specified interval specific to an AC.

In [5],[6], Gaur et al. have presented a scheme of randomly selecting AIFSN within certain predefined range for each AC. [5]-[6], have suggested that uniform randomization of AIFSN leads to higher system throughput. They have presented their results based on two different enhancement schemes; *Finer Prioritization with an AC* and *Traffic Spread using unifrom PDF*. A typical home networking scenario is considered as where there are three video streams and optional BE and voice streams. As the available bandwidth fluctuates, the performance of all 3 video streams is affected. If there is not sufficient available bandwidth for all 3 streams, then the current EDCA channel access mechanism would lead to performance deterioration for all 3 video streams. The target of the scheme proposed by Gaur at al. is to allow for finer prioritization among the video streams without affecting the performance of higher priority traffic. The authors conducted the same simulation twice, first in the presence of 3 video streams only and second in the presence of 3 video streams and 2 voice streams. Unique mean AIFSN values (between 2 and 3) were assigned to all three video streams. The results showed that in both the cases, video stream with low AIFSN had higher throughput than the video stream with larger AIFSN which proved that finer prioritization within an AC is achievable using random AIFSN mechanism. The authors in [5],[6] conducted one more simulation to prove that random AIFSN mechanism leads to higher throughput in all the ACs. A simulation was run in a network scenario where traffics of 3 different ACs were present. When random AIFSN mechanism was implemented on one of the ACs, throughput of all the 3 ACs were slightly increased. This increment in system throughput can be attributed to the fact that random AIFSN mechanism leads to fewer collisions resulting in efficient channel usage. Although this scheme is effective for increasing throughput of the system, it does not consider the fairness among the users.

In [7], Lopez-Aguilera et al. have proposed a mechanism involving the desynchronizing of EDCA functioning by using time values for AIFS whose differences are not multiple of the slot time. Due to the fact that the different AIFSs are separated by values that are multiples of the slot time, and that the backoff time counter is slotted, under heavy-load system conditions the different priority levels work in a synchronized way: they can attempt for transmission simultaneously. This situation produces collisions between the transmissions of high priority frames with backoff time and of lower level frames without backoff time. The authors in [7] have evaluated the performance of the IEEE 802.11e when different access times (that are separated by values that are not multiples of the slot time) are assigned. Their proposed scheme avoids that stations belonging to different priority classes attempt for transmission simultaneously. Hence, they desynchronize the IEEE 802.11e working procedure and collisions between the different priority levels are avoided. [7] evaluates the values for AIFS of different AC (based on total number of different priority levels) according to following equation:

$$AIFSN_i = AIFSN_{initial} + (i+1)\frac{\sigma}{g} \quad , \qquad where \quad i = 0,\ldots g-1 \tag{3.2}$$

where σ is the SIFS interval and g is the number of different priority levels.

In [8], Wang et al. have introduced a differentiation enhanced adaptive EDCA (DE-AEDCA) mechanism which can adapt to different network congestions by calculating the collision rate of the sending data frames, dynamically adjusting the window zooming and maintaining an appropriate CW range. The random offset achieves further distinction of data frames competition parameters within the same priority, and reduces their conflict probability. Consequently, it cuts down the numbers of idle time slots caused by conflict, and improves the channel utilization. Wang et al. have presented DE-AEDCA mechanism in four steps. First step involves determining the collision rate in certain slot duration. Second step involves the calculation of new CW based on current weighted value of the collision rate:

$$CW_{new} = \min\{CW_{\max}, CW_{old} \times (1 + 2^{\varphi})\} \tag{3.3}$$

where φ is the current weighted value of collision rate, φ ∈ [0,1]. The scope of $(1+2^{\varphi})$ is [2, 3], thus the competition window of the AC can progressively increase in different multiples depending on collision rate of its data frame. The larger the value of φ is, the greater the progressively increasing multiples are, and vice versa, thus competition window can adaptively adjust depending on network status indication. The third step of the algorithm involves controlling the window size dynamically based on the current network state to avoid further competition which results from contention window decreasing too fast. The fourth and last step of DE-AEDCA includes the differentiation mechanism between same ACs. The idea is to mitigate the problem when the same AC data frames of different nodes compete with each other leading to the drastic decline of the whole network's performance when EDCA is under the high load. The avoidance time is random generated between 0 and CW. The delay time, which is decided by AIFS, is the time necessary to wait before avoidance. Usually, the waiting time before trying to transfer each AC data frame equals to the sum of the avoidance time and the delay time. The avoidance time is random generated between 0 and CW. So the basic idea of this algorithm is to increase the probability of the same AC choosing different competition parameter value by designing an added random offset to CW and AIFS as:

$$CW_{offset} = Random(0, CW_{offset}^{\max}) \tag{3.4}$$

$$AIFSN_{offset} = Random[N, M] \times aSlotTime\ , \tag{3.5}$$

where N and M are the range of AIFSN values for current AC.

In [9], Dong et al. have proposed a modified version of EDCA called Load Adaptive EDCA with Enhanced Service Differentiation (SD-AEDCA) which dynamically adjusts the CW parameter according to channel load conditions hence improving throughput and QoS for real-time services at heavy load condition. The channel load conditions can be inferred from local monitoring, or collected and distributed by AP. The exponentially weighted moving average of collision rate was utilized to indicate the channel load conditions, where collision rate was calculated using the number of collisions and the total number of frames sent during a constant period. Since the collision possibility is expected to be controlled at a considerably low level no matter whether the channel load is heavier or lighter, a new measure named as frozen rate is defined to provide an indication about contentions in an EDCA-based wireless LAN. During an EDCA backoff process, every time the channel is sensed busy, backoff timer is frozen consequently. The number of frozen times indicates implicitly the channel load conditions. Frozen Rate (FR) can be calculated as follows:

$$FR = \frac{F\_slots}{IB\_slots + 1} \quad , \tag{3.6}$$

where *F_slots* denotes the number of frozen times during one turn of backoff process and *IB_slots* denotes the initial value of backoff counter in slot times. The value of FR lies in the range of [0,1). A big value of FR indicates that there are more contentions on the wireless medium. Assuming the channel load conditions will not change abruptly, the size of contention window can therefore be adjusted dynamically based on FR estimated during last turn of back off process. If a real-time frame waits too long at sender side for transmission, the frame will eventually be discarded at receiver side by upper applications. In that case, even though the corresponding EDCAF has won the transmission opportunity through the backoff process, the frame ought to be dropped directly at sender side so as not to do the meaningless transmission. In SD-AEDCA, a threshold waiting time threshold is defined for real-time frames. When the backoff process finishes, if the waiting time (WT) of a real-time frame is greater than WI threshold, it will be discarded directly at sender side; otherwise the frame will be transmitted as standard EDCA specifies. Most of Wireless LAN transmission collisions are attributed to non real-time frames for their larger size than real-time frames [7]. So the transmission of non real-time frames should be suppressed in the case of heavy load conditions.

When a collision occurs during transmission, the EDCAF has to reenter the backoff process. At that point, CW should be adjusted adaptively followed by re-initialization of BC. Owing to the hard QoS requirement of real-time frames on transmission latency, the frames with longer WT should be transmitted as soon as possible while trying to avoid collisions. A threshold is defined for real-time frames. If WT is less than the threshold at the moment of collision occurring, which means the waiting time of the frame is rather short, CW should be increased to reduce collision possibility. If WT is greater than threshold upon collisions, which means the frame has been waiting to be transmitted for a long time, CW should be decreased to grant more transmission opportunity to the frame, preventing it from being dropped for the sake of transmission timeout.

Although all of the aforementioned schemes offer certain degree of random offsets which achieve further distinction of data frame's contention parameters and enhances the performance of EDCA, the fairness levels gained are still not optimal. The reason for this is because; current performance of the individual nodes is not considered; which is a very sensitive entity for fairness increment. The proposed mechanism of IFMA provides differentiation among traffics of the same category by mapping the individual node's channel access probability directly to its observed real time performance. As a result IFMA makes the poorly performing nodes prone to the faster channel access thereby increasing the *Intraclass Fairness* without compromising the interclass differentiation.

C. Performance Characterization of Individual Nodes

The main goal of IFMA is the fairness increment among flows of the same traffic category. Therefore it is very important to consider the individual performance of the nodes which are generating the traffic. The basic idea is to select relatively good values for contention parameters on nodes with bad performance and relatively bad values for contention parameters on nodes with good performance.

While considering the performance of the nodes, it only makes sense to consider its current performance. The information about its performance in the past is of no relevance in our case. Therefore we need to consider a window frame of certain time interval and calculate NPLR based on node's performance within that interval only. IEEE 802.11 includes an inbuilt management frame called beacon frame which is suitable for our requirement. Beacon frame acts as a periodic heartbeat for WLAN, enabling stations to establish and maintain communications in an orderly fashion. In general, beacon interval is set to 100ms, which provides good performance for most applications. After completion of each beacon interval, we recalculate the performance of the node and use it to derive appropriate contention parameter values which would be used by the node until next beacon arrives.

Performances of the individual nodes are measured by considering two input metrics; *Packet Loss Rate per AC* and *Medium Access Failure Count per AC*. So, four performance values (one for each AC) are generated for each node.

1. Packet Loss Rate per AC

Packets can be lost due to following reasons;

i) Dropped from transmission queue,
ii) Dropped by exceeding the retry limit or

iii) Dropped in the path due to bad channel conditions.

For real-time traffics (assuming general network traffic conditions), packets are less likely to be dropped by exceeding retry limit whereas the packets dropped in the transmission queue accounts for most of the PLR.

2. Medium Access Failure Count per AC

Although PLR is considered the main metric for evaluating node performance, in IFMA we require medium access failure count as well for accurately measuring the node performance. When nodes have packets to send, they compete to win the channel access. Whether a node succeeds in few tries or it takes many retries to with the contention determines the potential throughput of the node. PLR only measure the failure rate of packets which were sent but it cannot measure the count of channel access opportunities that nodes get for sending packets. In IFMA, each time a node fails to access the medium; it slightly increases its probability to choose a better contention parameter value next time.

D. Modifications in Contention Parameter, AIFSN

In EDCA, smaller AIFS leads to higher probability for channel access and larger AIFS leads to lower probability for channel access. To support inter-AC differentiation, different access categories have different values for AIFSN. These values are pre-specified and remain constant throughout the process for each AC. The standardized value of AIFSN for four different ACs in EDCA is summarized in Table 2-1.

However in EDCA, all the flows of the same traffic category have the same AIFSN. Hence there is no inbuilt provision for intra-AC differentiation. In our novel scheme of IFMA, we extend the significance of AIFSN to Intraclass Fairness by increasing the range of possible values and assigning multiple values of AIFSN for each category. The modified range of AIFSN values for each AC is summarized in Table 3-1. It is noteworthy to mention that the lower bound of AIFSN for VO must be greater than 0 so as to maintain the priority of the ACK and Clear-to-Send (CTS) packets in the system over the data packets. In Eqn. (2.1) if AIFSN=0, AIFS will be equal to SIFS which could bring collision of ACK or CTS packets with data packets since these packets are transmitted when the medium is found to be idle for SIFS after receiving data and RTS packets.

Table 3- 1: Modified AIFSN range for different ACs in IFMA

Access Category (AC)	Min. AIFSN(M)	Max. AIFSN(N)
Voice (VO)	2	7
Video (VI)	2	7
Best-Effort (BE)	8	11
Background (BK)	12	15

1. Randomization of AIFSN

The exact value of AIFSN to be used is randomly selected among its specified range of values with a non-uniform distribution (details in the following section). We tune the randomization distribution in such a way that QSTs which are experiencing higher packet loss will select smaller AIFSN and QSTs experiencing lower packet loss will select larger AIFSN. The extended range of AIFSN values also helps in reducing the congestion in the system which leads to reduced collision hence increasing the throughput of the system.

2. Analysis and Adaptation of AIFSN

After assigning a specific range of values to each AC, our next step is to select the most appropriate AIFSN within the range for each user based on the traffic category and performance experienced by the user for that traffic category. An important point to be noted is that unlike in EDCA, QSTs in our scheme could select AIFSN which can be different from AIFSN selected by other QSTs of the same AC and unlike EDCA, AIFSN value selected by a specific QST for each AC are constantly changing depending upon the performance of the QST itself.

To utilize PLR information in the AIFSN randomization function, we first define a new metric called Normalized PLR (NPLR) which is simply a ratio of the perceived PLR to the maximum allowed PLR.

$$NPLR = \frac{PLR}{Maximum\ allowed\ PLR}. \tag{3.1}$$

Based on the perceived NPLR each flow determines its AIFSN for the upcoming access. AIFSN is determined using a special random number generator where the generated number follows the following probability distribution function (pdf):

$$pdf(n) = NPLR * (1 - NPLR)^{n-1}, \qquad n = M, M+1, ..., N. \tag{3.2}$$

where M and N denotes the lower and upper bounds of the AIFSN range as defined in Table 3-1. PLR and NPLR both share the same characteristics i.e. they both measure the failure rate of the QST and their value is always between 0 and 1. But we use of NPLR instead of PLR in the above pdf equation because NPLR is more sensitive to packet loss than PLR. Figure 3-1 depicts the relationship between NPLR and AIFSN for two different values of NPLR. For different values of NPLR, nature of the curve remains the same; only the slope of the curve gets changed. For weak flows, (QSTs experiencing higher NPLR), the probability of selecting smaller AIFSN is higher whereas for stronger flows (QSTs experiencing smaller NPLR), probability of selecting any AIFSN is almost same.

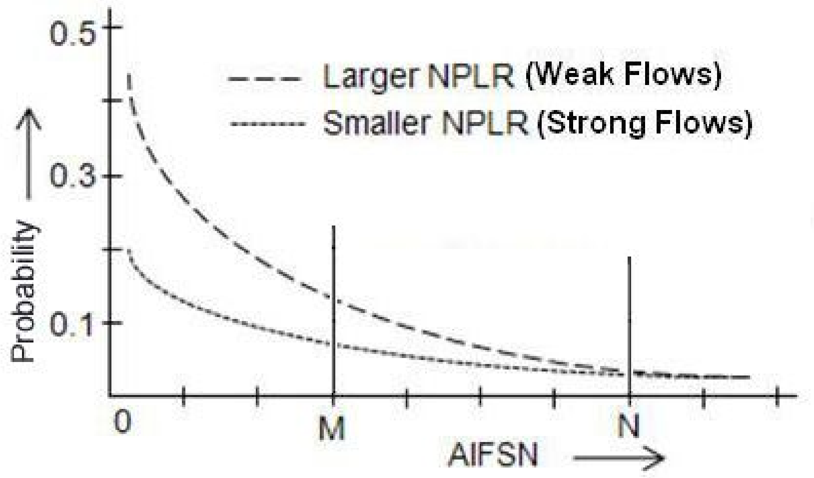


Figure 3- 1: pdf for randomization of AIFSN according to the perceived NPLR.

E. Modifications in Contention Parameter, CW

In EDCA, smaller CW leads to faster probability for channel access and larger CW leads to slower probability for channel access. Apart from the faster or slower channel access probability, CW also serves another important purpose which is to reduce traffic congestion in the network. To support inter-AC differentiation, different access categories have different values for CW. These values are pre-specified and remain constant throughout the process for each AC. The standardized value of AIFSN for four different ACs in EDCA is summarized in Table 2-1.

However in EDCA, all flows of the same traffic category have the same minimum and maximum CW. Hence there is no inbuilt provision for intra-AC differentiation. In our scheme of IFMA, we extend the significance of CW to Intraclass Fairness by manipulating the range of between CWmin and CWmax adaptively according to the individual performance of the node.

1. Analysis and Adaptation of CW

In IFMA, the modifications done in the contention parameter AIFSN is more effective for real time traffic in increasing the fairness and throughput as well. But we found out the same change is not in favor of background traffics in the network because although the intraclass fairness is increased, it further reduces the probability of channel access hence reducing the throughput of background traffics. To mitigate this adverse effect in the background traffics, we implement similar adaptation techniques in contention windows as well. A noteworthy point is that this scheme of adaptive CW is only implemented on background traffics and not on real time traffics. This is because; the main goal of CW adaptation is to reduce the adverse effects on background traffics caused by IFMA. Furthermore, the range of CW in real-time traffic is very small as compared to background traffic so this scheme of adaptive CW would not be very effective for real time traffics.

In legacy EDCA, a backoff timer is chosen randomly between $[0,CW_i]$, where CW_i is the value of contention window in the i^{th} retry of sending the data packets. For background traffics, CW_0 equals the CWmin which is 31. When the first attempt to the send the data packet is unsuccessful, a new backoff value is randomly generated using the value of contention window as CW_1. In legacy EDCA, value of contention window is doubled on each unsuccessful transmission until the AC specific maximum CW is reached, i.e., $CW_i = 2*CW_{i-1}$. Therefore CW_1 equals 62 for background traffics. Doubling the value of CW in each unsuccessful transmission has the benefit of congestion reduction in the network. If the network is suffering from high collision, then increasing the value of CW helps to increase backoff counter which reduces the congestion and thus reduces the collisions in the network. But trying to reduce congestion in such way also has the adverse effect of throughput reduction in the system as packets have to wait for longer time to be transmitted. Therefore one should be very careful about the tradeoff.

In IFMA, adaptation of CW involves the selection of CW based on the individual performance of the node. Unlike doubling the value of CW on each unsuccessful transmission (as in legacy EDCA), in IFMA, we decide upon the most appropriate value for CW depending upon the PLR experienced by the node on the particular background AC. To utilize PLR information in the CW adaptation function, we make use of the metric NPLR which we defined earlier in section II, Eqn. (3.1). Based on the perceived NPLR each flow determines its CW for the upcoming access as follows:

$$CW_i = CW_{i-1} \times \sigma \text{ ,} \tag{3.3}$$

where σ is the CW increment factor whose value is always in between 1.5 and 2.5. σ is determined using a random number generator where the generated number follows the following probability distribution function (pdf):

$$pdf(\sigma) = NPLR * (1 - NPLR)^{\sigma - 1}, \qquad 1.5 \leq \sigma \leq 2.5 \text{ .} \tag{3.4}$$

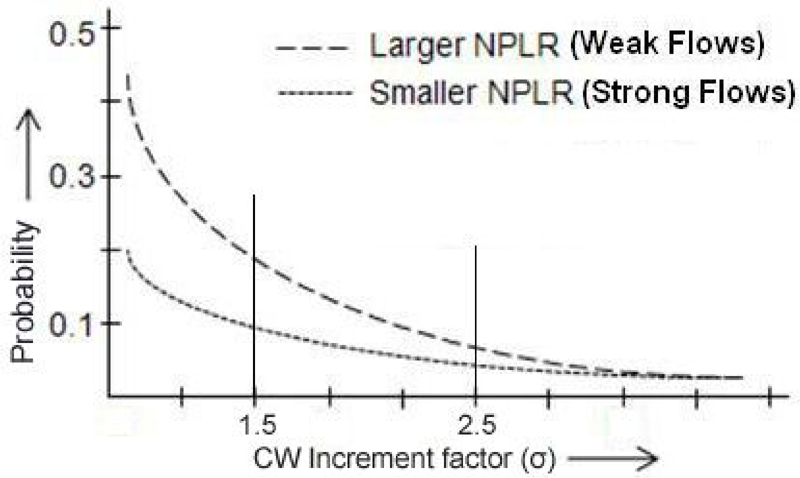


Figure 3- 2: pdf for randomization of CW increment factor according to the perceived NPLR.

Figure 3-2 depicts the relationship between NPLR and σ for two different values of NPLR. For different values of NPLR, nature of the curve remains the same; only the slope of the curve gets changed. For weak flows, (QSTs experiencing higher NPLR), the probability of selecting smaller σ is higher whereas for stronger flows (QSTs experiencing smaller NPLR), probability of selecting any σ is almost the same.

According to Fig. 3-2, in adequate network scenario, when a new backoff value is generated, value of CW to be used is roughly 2 times the previous CW used by the node. But when the node is highly suffering on PLR, the new CW is roughly 1.5 to 2 times the previous CW. This allows faster channel access to highly suffering nodes supporting our main goal of intraclass fairness. The added benefits offered by this scheme is the certain degree of random offsets which achieves further distinction of data frame's contention parameters.

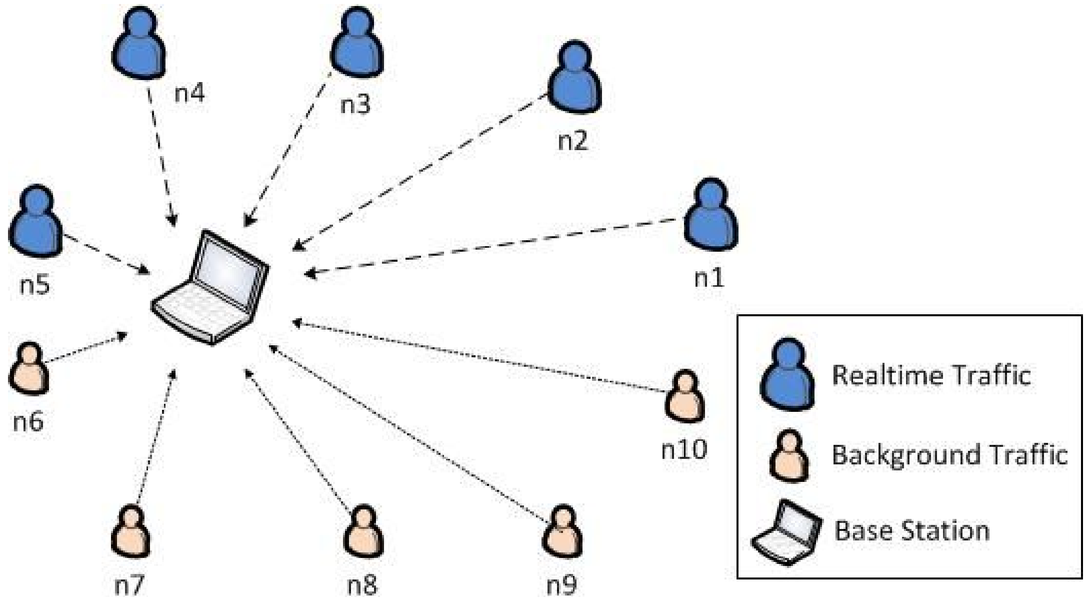


Figure 3- 3: Simulation scenario depicting topology and traffic flow. Half of the users are sending real time data whereas the other halves are sending background data to the same base station.

F. Performance Evaluation

We conducted our simulation on Network Simulator 2.28. The EDCA model was derived from a pre-existing model "An IEEE 802.11e EDCA and CFB Simulation Model for ns-2" developed by Telecommunication Networks (TKN). We carried out the simulation with star topology and NAOH routing agent. Traffics of two different ACs (Real-time and Background) were generated as Poisson distribution with an average of 200 packets per second. Figure 3-3 depicts the topology and traffic flow scenario used in the simulation. Some biasness among the nodes were introduced by manipulating their distance with respect to the central station. The purpose of introducing this biasness is to get uneven performances from the nodes, which we would try to mitigate by implementing IFMA in the same scenario. We carried out the performance analysis of our scheme and compared it with the legacy EDCA scheme on two performance metrics: *Fairness in Packet Loss Ratio* and *Fairness in Throughput*. Additionally, we also performed *delay analysis* of the proposed scheme.

1. Fairness in PLR

Figure 3-4 depicts the comparison between PLR in case of legacy EDCA and in case of IFMA. PLR experienced by users with real-time traffic are shown in Fig. 3-4(a). This result gives us two important information. First, PLR in the proposed scheme of IFMA is less than PLR in legacy EDCA for all the users with real-time traffic. The average PLR is reduced from 0.08 in EDCA to 0.03 in IFMA. The second information to perceive is that the variation of PLR values in IFMA is less than that in legacy EDCA which indicates higher fairness in terms of PLR in IFMA.

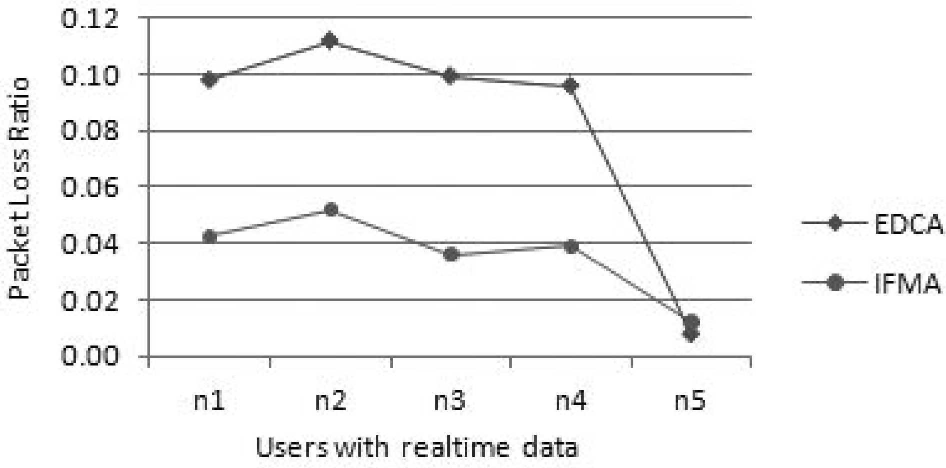
Fairness among different values can be quantitatively measured as a degree of closeness between the observed values. In our thesis, we define the performance metric fairness, f, as follows:

$$f = \frac{1}{\sigma + 1} , \tag{3.5}$$

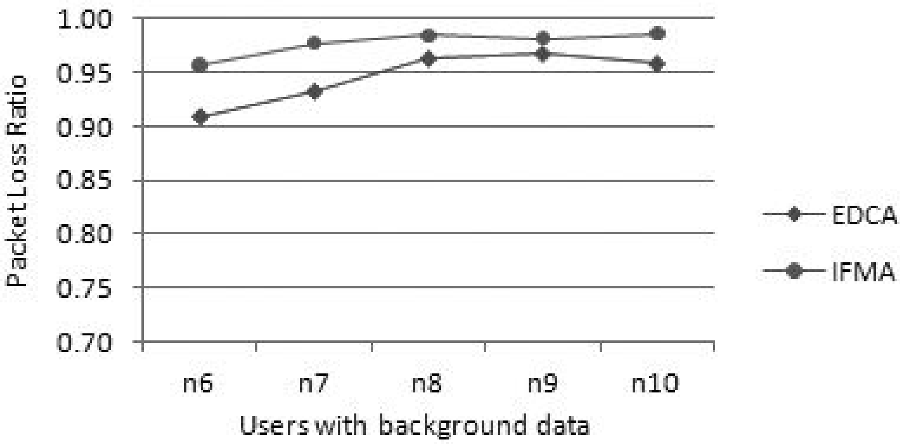
where σ is the standard deviation of the observed values. The result ranges from 0^+ (worst case) to 1 (best case) and it is maximum when all observations have equal value.

In Fig. 3-4(a), we found that the fairness was increased from 0.959 in legacy EDCA to 0.982 in IFMA. The exceptionally low PLR for the user n5 in EDCA is due to the explicit biasness that we introduced by manipulating node distances from base station (user n5 is very close to base station as compared to other nodes). The effect of this biasness seems to be reduced in IFMA which refers to increment in fairness.

PLR experienced by users with background traffic are shown in Fig. 3-4(b). Here, the performance of IFMA in terms of PLR is not good since it increases slightly in IFMA by 3%. However, IFMA focuses more on *Intraclass Fairness* which is increased in case of background traffic as well. In Fig. 3-4(b), we found that the fairness was increased from 0.975 in legacy EDCA to 0.988 in IFMA.



(a) PLR of individual users with real time traffic.



(b) PLR of individual users with background traffic.

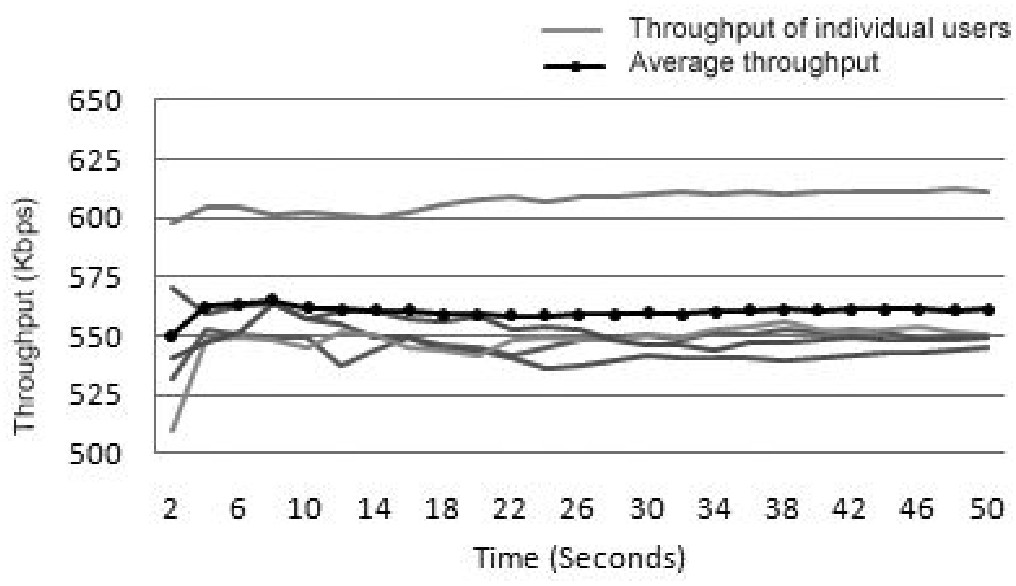
Figure 3- 4: PLR comparison between legacy EDCA and proposed IFMA.

2. Fairness in Throughput

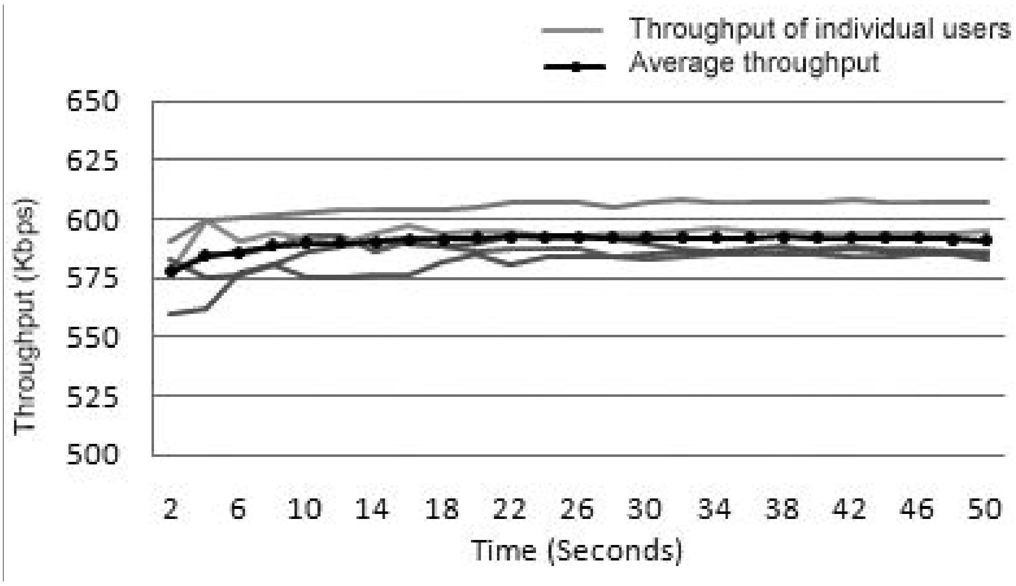
Figure 3-5 depicts the comparison between throughput experienced by nodes with real-time traffic in legacy EDCA (Fig. 3-5(a)) and in the proposed scheme of IFMA (Fig. 3-5(b)). The results are shown with reference to time axis. In Fig. 3-5(a), individual throughput of the nodes with real-time traffic ranges from 540kbps to 610kbps. The main goal of this paper was to increase fairness among users with the same traffic priority, the result of which can be seen in Fig. 3-5(b), where the range of throughput confines from 575kbps to 605kbps. Similar as measuring fairness in PLR, we measure fairness in throughput according to eqn. (3.5). We found that the fairness was increased from 0.034 in legacy EDCA to 0.091 in IFMA which signifies considerable fairness increment. Additionally, the average throughput is not compromised for the fairness increment because there is also an increment of average throughput from 561kbps in legacy EDCA to 590kbps in IFMA.

Figure 3-6 depicts the comparison between throughput experienced by nodes with background traffic in legacy EDCA (Fig. 3-6(a)) and in the proposed scheme of IFMA (Fig. 3-6(b)). The results are shown with reference to time axis. In Fig. 3-6(a), individual throughput of the nodes with background traffic ranges from 20kbps to 55kbps. This range is reduced in Fig. 3-6(b), where it confines from 7kbps to 25kbps signifying considerable fairness increment. The fairness was increased from 0.060 in legacy EDCA to 0.119 in IFMA.

Unlike in the case of real-time traffics, average throughput was found to be decreased in the case of background traffics. Nevertheless, fairness has been increased in all the cases which is the main target of the proposed scheme.

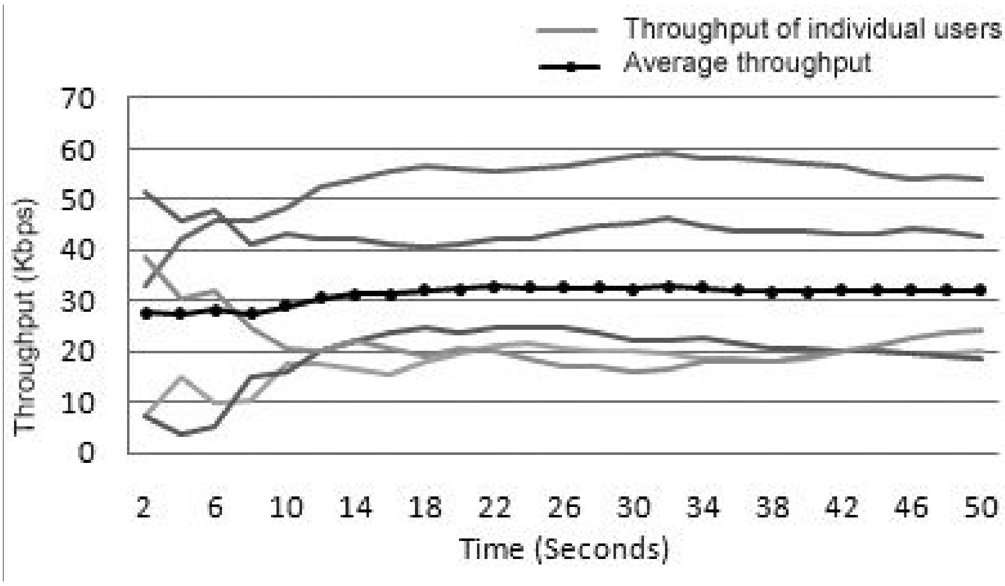


(a) Throughput of users with real-time traffic in EDCA.

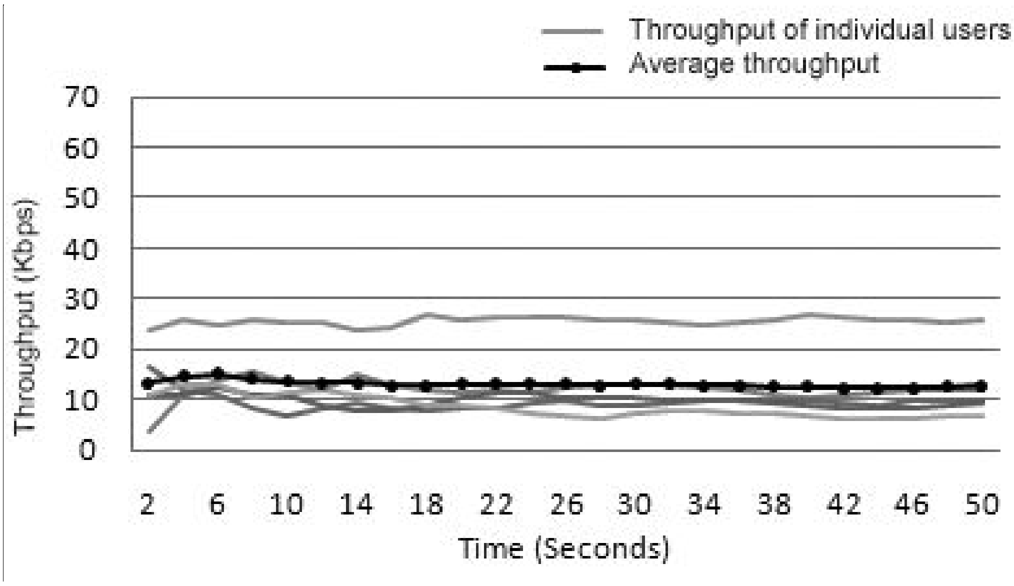


(b) Throughput of users with real-time traffic in IFMA.

Figure 3- 5: Throughput comparison between legacy EDCA and proposed IFMA scheme for real-time traffic in the presence of background traffic.



(a) Throughput of users with background traffic in EDCA.



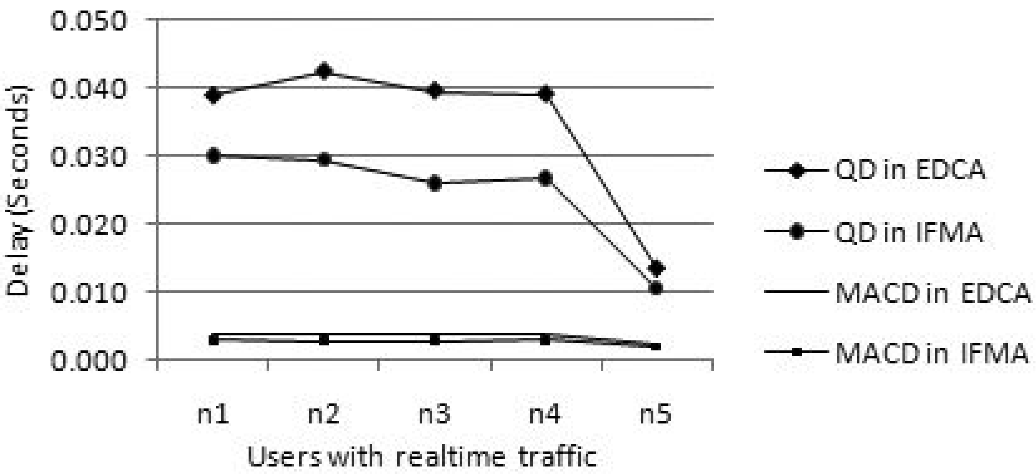
(b) Throughput of users with background traffic in IFMA.

Figure 3- 6: Throughput comparison between legacy EDCA and proposed IFMA scheme for background traffic in the presence of real-time traffic.

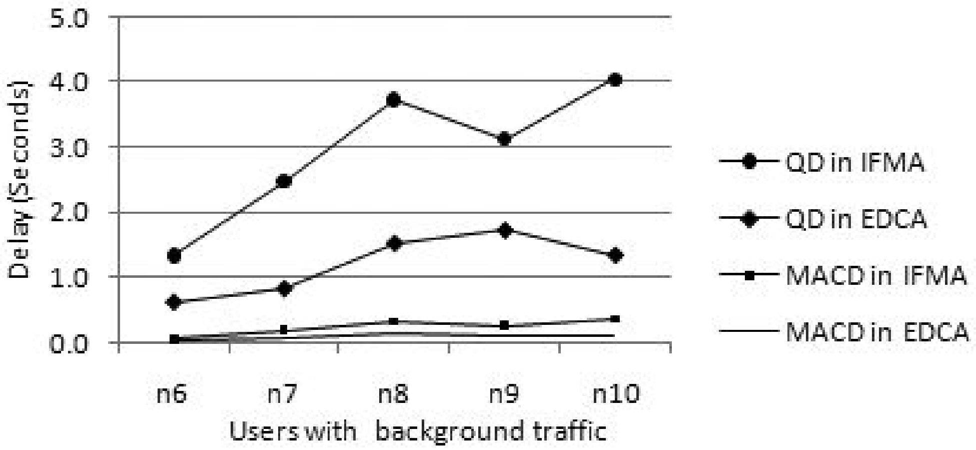
3. Delay Analysis

Delay performance of a scheme can be measured by the means of two metrics; Queuing Delay (QD) and Media Access Delay (MACD). QD is the timespan from the birth of a packet till the node initiates its transmission (in other words it is the time during which the packet stays in transmission buffer). MACD is the timespan from the start of packet transmission till the successful reception of that packet at the receiving node. QD accounts for most of the total delay because it is much larger than MACD. Figure 3-7(a) shows the comparison between delays experienced by the users with real-time traffic in EDCA and IFMA. Same metrics comparison for the users with background traffic is presented in Fig. 3-7(b). From Fig. 3-7(a) and Fig. 3-7(b), we can conclude that there is a significant decrease in delays (both QD and MACD) experienced by real-time traffics in case of IFMA. But the same is not true in case of background traffics.

Figure 3-8 shows the delays experienced by users when the network is free of background traffics (i.e. all the users are sending only real time traffics). In this case, the average QD is reduced from 59ms in EDCA to 35ms in IFMA and the average MACD is reduced from 6.3ms in EDCA to 4.2ms in IFMA. This shows that the proposed scheme is in favor of real-time traffics whether the background traffics are present of not.



(a) Delays experienced by users with real-time traffic.



(b) Delays experienced by users with background traffic.

Figure 3- 7: Delay comparisons between legacy EDCA and proposed IFMA scheme in the presence of background traffic.

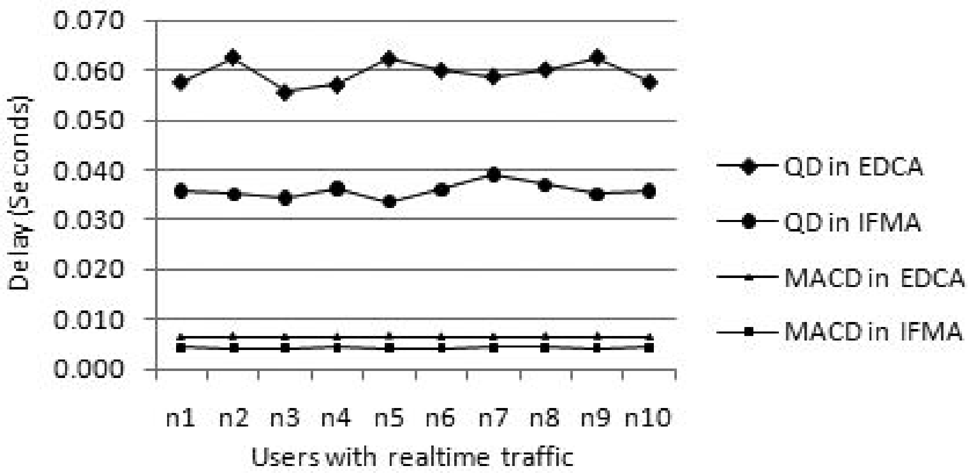


Figure 3-8: Delay comparisons between legacy EDCA and proposed IFMA scheme in the absence of background traffic.

IV. Conclusion and Future Work

The contributions we made in fairness enhancement in IEEE 802.11e were presented in chapter 3. We developed a new MAC protocol for intraclass fairness enhancement in IEEE 802.11e called Intraclass Fair Medium Access (IFMA). The protocol is based on a packet loss fair medium access scheme for real time applications in IEEE 802.11e networks. It is based on the concept of prioritization of contention parameters with respect to the perceived PLR. Its main purpose is to increase fairness among users with the same traffic priority; i.e. to increase *intraclass fairness*. We implemented the idea of randomization combined with adaptive selection of contention parameter values, based on the individual performance of the users. Certain amounts of biasness were introduced in the randomization process in favor of poorly performing users to increase their performance. Simulation results show that our novel scheme highly increases fairness among the users as well as it enhances the performance of the network.

The operation of IFMA can be divided into two parts; Modifications in the contention parameters (AIFSN and CW) and adaptive randomization in the contention parameters. Firstly, we modified AIFSN value sets such that different values could be chosen for AIFSN in the runtime instead of a static pre-specified value. Implementation of range of values for AIFSN instead of a single value helps the system to achieve random offsets among the traffic flows. This in turn allows the system to reduce collisions and increase throughput. Secondly, we introduced biasness in the random selection process in favor of low performing nodes. This was achieved by probabilistically mapping the current performance of the users with the assigned range of AIFSN values. Higher the user performance is, lower will be the probability of selecting smaller AIFSN and vice versa. This allows faster channel access to the poorly performing users, which highly increases the intraclass fairness in the system. Similar modifications were made in the process of CW selection for calculating backoff values.

We verified our claims in the researched IFMA protocol by running a simulation model and comparing its performance with that of legacy EDCA. We focused mainly on the performance metrics of fairness increment (among users of the same traffic priority). Simulation results showed that IFMA highly outperforms EDCA in terms of fairness in throughput as well as fairness in PLR of individual users.

Apart from fairness increment, IFMA also outperformed EDCA in various other performance metrics like PLR, system throughput and delay time for real time traffics. But in case of background traffic, although the fairness was increased among the users, some tradeoffs were made on throughput. The cause of decrease in throughput for background traffic was the use of higher AIFSN values as a result of increment in AIFSN range. We tried to mitigate this problem by modifying the backoff process for backgro/und traffics. We believe that further enhancement can be made in this part of our study by finely tuning the selection process of appropriate contention window values. This is included as a future work related to the research works of this thesis.

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ABSTRACT

A Study on Fair Medium Allocation for Intraclass Fairness Enhancement in IEEE 802.11e

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Fair resource allocation is a widely studied topic in synchronized and centralized networks where channel resource is allocated periodically by a centralized controller. Planning and controlling the allocation of channel resources to different users might be based on aspects like the observed throughput and Packet Loss Rate (PLR) of traffics from individual users. However, it is not simple to implement such fair access mechanism in the non-synchronous and distributed infrastructure-less networks where there is no centralized unit to monitor and control the network entities. Since wireless medium is far more unpredictable and prone to errors in comparison to its wiredline counterparts, the need to acknowledge the issue of fairness becomes higher in such networks.

In this thesis, we studied different types of medium allocation techniques in IEEE 802.11e and developed a new protocol that offers Intra-class Fair Medium Access (IFMA) in infrastructure-less wireless networks. The proposed IFMA mechanism is designed considering the popular IEEE 802.11e MAC. The fundamental concept of the proposed scheme is to tune the MAC contention parameters namely Arbitration Inter-frame Space Number (AIFSN) and Contention Window (CW) in such a way that the contending users with higher PLR are provisioned higher priority to access the medium.

The proposed mechanism of IFMA provides differentiation among traffics of the same category by mapping the individual node's channel access probability directly to its observed real time performance. As a result, IFMA makes the poorly performing nodes prone to the faster channel access, and thereby increasing the intraclass fairness without compromising the existing interclass differentiation.

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