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Analysis of Starvation Problem in Wireless LANs

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Abstract: Quality of Service (QoS) is essential for real time applications. IEEE 802.11e is aimed to facilitate all the necessities for QoS and it is an amendment to the basic 802.11. This uses four queues for differentiated traffics namely Voice, Video, Best effort (BE) and Background (BK). IEEE 802.11e gives highest priority to voice and video queues and transmits according to Arbitration Inter frame Space, Contention Window and Transmission opportunity limit. This causes the starvation for BE and BK traffic. BE and BK traffic is common in emails, social networking and web browsing which are the widely used applications. BE and BK traffics should not be starved due to their need in crucial applications. Enhancements of IEEE 802.11e in order to improve the QoS are IEEE 802.11aa and IEEE 802.11ac. They concentrated to ensure best QoS for voice and video but not for BE and BK traffics. In this paper we investigated the reasons for starvation and analyzed some solutions that had been proposed to solve the starvation. This paper also proposes the research directions which balances the tradeoff between high priority and low priority traffic.

Keywords: Quality of Service, High priority traffic, Starvation, Low priority traffic, Voice, Video, Best Effort, Background.

1. INTRODUCTION

QoS is defined as "the ability to ensure the quality of the end user experience" by its broadest sense of International Telecommunication Union (ITU) [1]. This is achieved by maximizing the bandwidth and associated network performance parameters such as delay, jitter, throughput, and latency. QoS is realized by supervising and maintaining the network resources and by providing the precedence for different types of traffics such as voice, video, and data. QoS is aimed to apply for the traffics such as Voice Over IP (VOIP), Video on Demand, HDTV, and online gaming. According to the Universal Mobile Communication System (UMTS) there are four QoS classes:

- Conversational Class
- Streaming Class
- Interactive Class
- Background Class [2].

The Description of the four classes and examples are given in Table 1.

Now a day's Internet users are increasing due to its ease of use and fast data transmission. The network performance requirements must be met to satisfy all the users of the Internet. Network convergence refers to the availability of voice, video and data services inside one network. In alternative words, one pipe is employed to deliver all styles of communication services. The method of Network Convergence is primarily driven by development of technology and demand. One main goal of such integration is to deliver higher

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Table 1
Descriptions of QoS classes

Traffic class	*Description*	*Example*
Conversational Class(Real Time)	Preserve time relation (variation) between information entities of the stream, conversational pattern (stringent and low delay)	Voice
Streaming Class(Real Time)	Preserve time relation (variation) between information entities of the stream	Streaming video
Interactive Class(Best Effort)	Request response pattern	Web browsing
Background Class	Destination is not expecting the data within a certain time	Telemetry, e-mails

services and lower costs to users. Users ready to access a wider vary of services, opt for among a lot of service suppliers. On the opposite hand, convergence permits service suppliers to adopt new business models, provide innovative services, and enter new markets.

A converged network [3] supports different kinds of applications like voice, video, and data at the same time over a standard infrastructure. Accommodating these applications that have totally different sensitivities and necessities are difficult to the network engineers. We are associated with an era marked by tremendous international growth in mobile-data subscribers and traffic. Surveys show that mobile information subscribers can grow from 564.9 million in 2010 to 2.6 billion in 2016. Today's mobile broadband networks carry multi play services that share radio access and core network resources. Additionally to best-effort services, wireless networks should support delay-sensitive, time period services and all these are associated with QoS as shown in Fig 1. In this paper we considered only wireless services. The wireless converged networks supports by combining all the above services into three broad categories, and all three are strongly connected with QoS as shown in Fig 1. Every service has totally different QoS necessities in terms of packet delay tolerance, acceptable packet loss rates, and needed minimum bit rates.

As mobile networks evolve to high-speed, IP-based infrastructure, the wireless market is making certain high-quality services by developing QoS and policy-management techniques additionally to adding network capability. These techniques are designed to make sure application quality, enable operators to supply differentiated services to users, manage network congestion, and recoup the substantial sums that are invested with in building out new networks. Many of the users are using the real time applications such as voice, video conferencing and video streaming. With respect to the demand of the real time applications, many researchers are designing and deploying the protocols to provide the best QoS for them. Indeed the traffics

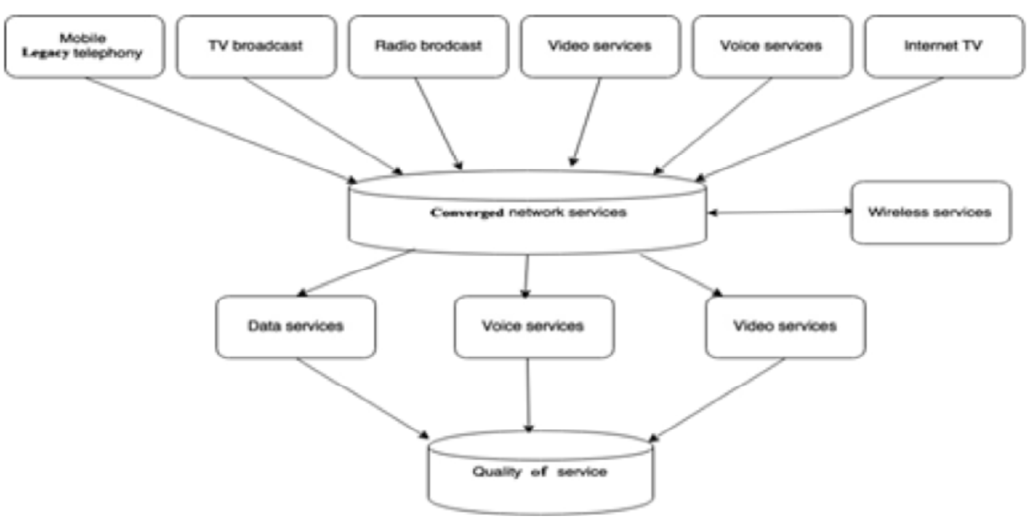

Figure 1: Network Convergence and QoS

BE and BK are involved in crucial areas like e-mails, texting and browsing websites. E-mail is an effective business communication tool. Texting and web browsing are emergent in the field of social networking and Internet respectively.

In Wireless Local Area Networks (WLANs) the Medium Access Control layer is shared among the multiple clients and medium bandwidth is limited. All the devices are within the range of each other and any client or access point may transmit the data at a time and remaining all others are in Idle or listening state. This causes the congestion in the network and increases the data transmission failures. To Access the medium in an efficient way the IEEE Task group 802.11 proposed some medium access protocols and some advancements to provide QoS. The protocols formerly designed to provide QoS for Real time applications achieved the same by differentiating the traffics. But they ignored the importance of the BE and BK traffics. There is need to put them under the QoS classes. The IEEE Task Group 802.11e is aimed to provide the QoS for voice and video. This protocol is not concerned about the QoS of the BE and BK. If the Network is overloaded with voice and video then BE and BK are starved by them. In view of significance of BE and BK, they are to be transmitted with at least minimum precedence and should not starve even after the network is saturated with high priority traffics. EDCF works based on the contention medium access mechanism and HCF is based on the poling mechanism. In 802.11e EDCF, the contention window may be expanded or reduced by using persistent factor(PF) for every unsuccessful transmission. If the Collision occurs the time sensitive applications attempting to retransmit can send in smaller back off range than its first failed attempt to reduce the delay and jitter.

IEEE 802.11e differentiates the services into four access categories and separate queues are maintained for every category. All the categories are given different priorities by using their Contention Window (CW), Inter frame Space(IFS) and Transmission opportunities(TXOP). The Real time applications VOIP, Video Conferencing, and online gaming served with high priority using Voice(VO) and Video(VI) queues and Best Effort and Background traffics are served with low priority using Best Effort(BE) and Back ground(BK) queues. Each of the Category contends for the medium when they are ready with data but the queue with lower CW value, will get the access first, remaining has to wait for next back off range. In Practice the queues VO and VI get the access first using low CW and Arbitration Inter Frame Space(AIFS) for every transmission. If Network is overloaded with VO and VI traffic the queues BE and BK are starved by other two. The “best effort” service has played a major role in the success of the Internet services. The BE and BK are preferably served even if the network is saturated with VO and VI traffics because as shown in Table 1 the QoS is to be maintained for emails and web browsing. However this protocol don’t deal with unicast and multicasting. Due to this, the protocol 802.11e is not sure to satisfies the video traffic since it is transmitting with only single queue. There are different types of frames for video traffic. Video and video conferencing frames are coded with different codec types, and transmission using single queue results in increased delay for video conferencing frames. To Differentiate the video flows the protocol IEEE 802.11aa extended the EDCF prioritization mechanism. In this two extra queues, Alternate VO(AVO) and Alternate VI (AVI) are added. The AVO and AVI are incorporated with VO and VI respectively in EDCF. Surely and completely the 802.11aa standard has also ignored the importance of the BE and BK traffics. Once the TXOP is sanctioned, the any one of the queue(either it is alternate or primary queue), it can transmits its frames until the TXOPlimit. In this case the BE and BK will starve. To achieve high throughput on multiple downlink transmissions the protocol IEEE 802.11ac defined some Rules. This TXOP policy in EDCF has a few limitations, i.e., TXOP is only aimed for the specific queue at the station. Due to this, other access category frames are not allowed to transmit. It is one of the reasons for starvation of the best effort and background traffics. To solve this Problem the 802.11ac proposed TXOP Sharing mechanism at access point (AP) by allowing AP to transmit simultaneously to multiple receiving stations. By deploying this mechanism the lower priority queues will get relief partially.

This paper contributes in the analysis of the starvation of lower priority queues in the QoS policies especially 802.11e. IEEE 802.11e is aimed to provide the QoS for time sensitive applications but doesn't consider the starvation of BE and BK. IEEE 802.11aa is aimed to provide better QoS for video conferencing and VOIP but ignored the importance of BE and BK. In this paper we present the analysis of the IEEE standards 802.11e, 802.11aa and 802.11ac to find the reasons for starvation. We reviewed the mechanisms to solve the starvation and presented few research directions.

2. POLICY DESCRIPTIONS AND THEIR ROLES IN STARVATION

2.1. Distributed Coordination Function (DCF)

In DCF, a station should transmit the data when and only the medium is idle. To reduce the probability of collision a station chooses a backoff interval randomly, and that should be less than or equal to the size of the CW using uniform distribution. When the medium is idle then backoff timer decreases by one at each time slot. Transmission starts whenever the backoff timer becomes zero. If any collision occurs during the transmission or if the transmission fails due to unwanted reasons, the station starts the backoff procedure. The CW value ranges from CWmin to CWmax. If the maximum retransmission attempts limit is reached, retransmission stops, and the packet is discarded by setting CW to CWmin. The RTS/CTS mechanism and basic access mechanism of IEEE 802.11 are shown in Fig 2. [4]

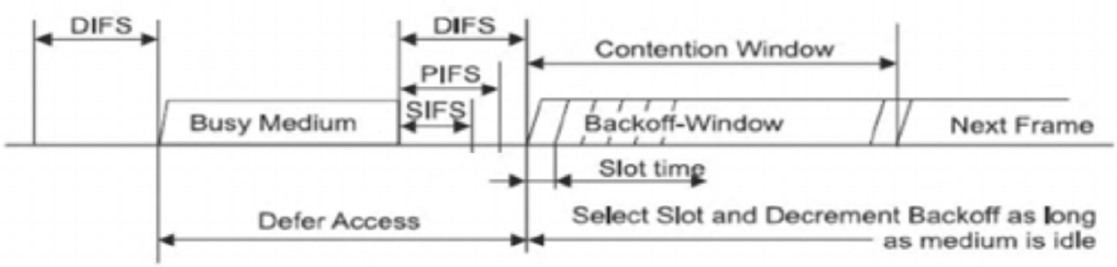

Figure 2.Working of DCF

(Source: from Reference [4])

Doubling the CW for every failure of the transmission causes delay increment drastically for all the traffics irrespective of its type. This protocol doesn't address the starvation because of its nature of transmission i.e., every frame (flow) is sent with same precedence. This treats all the frames as equal irrespective of its traffic type. Hence, no frame is starved by other and can transmit in the First come First Serve fashion. It causes the performance degradation of the network for the time sensitive applications such as VOIP, Video Streaming and others. In order to provide better QoS for time sensitive applications, the Task group IEEE 802.11e has amended the 802.11 protocol.

2.2. EDCF

Due to the limitations of DCF, the 802.11e defines a single Hybrid Coordination Function, HCF, which combines the functions of both DCF and PCF for QoS data transmission. In IEEE 802.11e works in two phases, Contention Period (CP) and Contention Free Period (CFP). EDCA is only used in CP. In EDCA, QoS is supported by introducing multiple access categories (ACs) in each QoS station (QSTA). EDCA defines four ACs, and every AC has its own priority to serve different types of traffic. Table 2 shows that how the user priorities noted in the IEEE 802.1D protocol are mapped to the ACs.

As shown in Fig. 3, each AC contends for TXOP using AC associated channel access parameters from the EDCA parameters set [5]. CW_{min} is one of them and can be different for different ACs. Smaller CW_{min} values are assigned to high priority classes to obtain quick access. Similar to CW_{min}, CW_{max} is also set for all

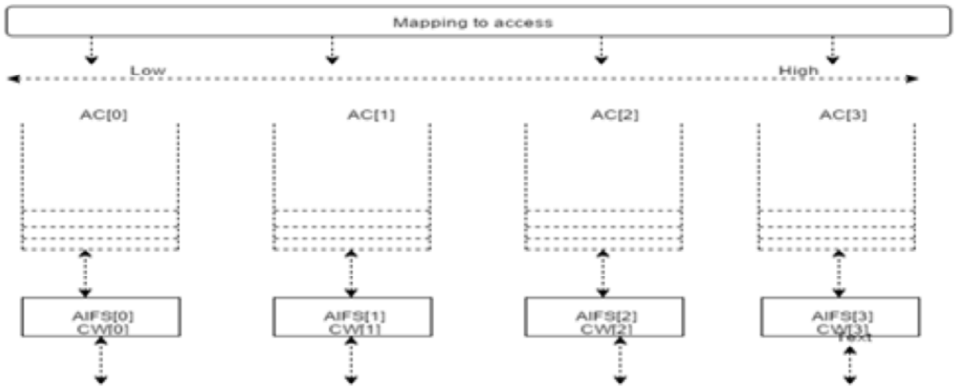

Figure 3. EDCA Mapping to access with four queues

(Source: from Reference [4])

ACs. Each AC starts its backoff procedure after the channel is idle for a period of AIFS[AC]. The AIFS[AC] is calculated for AC as

$$\text{AIFS[AC]} = \text{aSIFSTime} + \text{AIFSN[AC]} * \text{aSlotTime}——— \quad (1)$$

(i.e., Shorter IFS(SIFS) plus multiple time slots).

TXOP limit of AC is obtained via EDCA. During a TXOP, a station may be allowed to transmit multiple data frames from the same AC with a SIFS gap between an ACK and the subsequent data frame transmission.

Table 2
IEEE 802.1D user priorities mapping

802.1D User Priority	802.1D Designation	802.11e Access category	802.11aa Access category
7	Network Control(NC)	VO	AVO
6	Voice(VO)	VO	VO
5	Video(VI)	VI	VI
4	Controlled Local(CL)	VI	AVI
3	Excellent Effort(EE)	BE	BE
0	Best Effort(BE)	BE	BE
2	Spare(——)	BK	BK
1	Background(BK)	BK	BK

TXOP limit[AC] gives the limit for such a sequence of transmissions. By using the formula stated in (1) the queue is admitted. The Higher priority queues will get admitted first due to its lower CW and AIFS values. That admission remains longer due to its large TXOP limit. In this case the lower priority queue is not admitted and has to wait for long time. Thus there is no guarantee that BE and BK queues will get transmission opportunity. This causes the starvation of the BE and BK in saturated conditions. In addition to the starvation of the lower priority queues, this protocol didn't considered the frame types (I/P/B) of video traffic. Video is demanded by the user in different forms like video streaming, video conferencing and Internet TV. These applications are separated by frame types for the video traffic. This protocol treats that all video frames as equal. This mechanism degrades the performance of the network when user wants better performance for video conferencing and Internet TV.

2.3. The IEEE 802.11aa

Because of the expanding number of video streams there is a requirement for separation between individual Audio and Video streams. Consider an AP serving both a video conferencing and Internet TV. IEEE 802.11aa

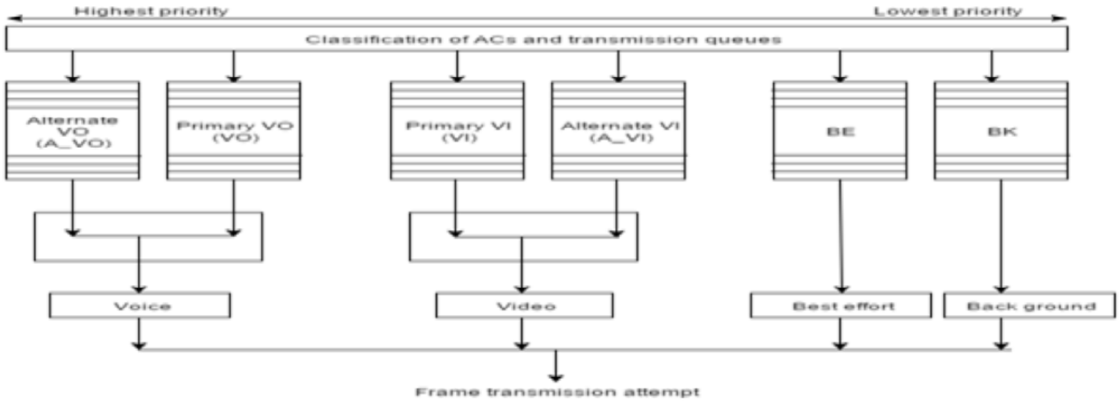

Figure 4: IEEE 802.11aa mechanism with six queues

(Source: from Reference [5])

separates the transmit queues for Voice (VO) and Video (VI) ACs into two (primary and alternate). Thus, there are six transmit queues altogether: Primary Voice (VO), Alternate Voice (AVO), Primary Video (VI), Alternate Video (AVI), Best Effort (BE), and Background (BK).

These queues are derived from the IEEE 802.1D user needs as shown in Table 2. The transmit queues are mapped to four autonomous EDCA capacities as shown in Fig. 4. A committed scheduler is used to maintain the VO and AVO (VI and AVI) queues in EDCA capacity. This is acknowledged utilizing credit-based schedulers (with two queues) as characterized in IEEE 802.1Q. This scheduler is designed so that frames from the higher need queues are chosen with a higher priority than lower priority queues. The EDCA capacity stays unaltered for every AC and information transmission is composed utilizing methodology characterized as a part of 802.11. In the case of MPEG streaming, the specific video frame types of the codec (I/P/B) can be appointed distinctive needs to guarantee that the most important ones (I frames) are given a higher QoS. Effortlessly, the choice based scheduling algorithm is not intervening in the admission procedure of BE and BK queues such that it works similar to the EDCA mechanism that causes the starvation of the lower priority queues. [5]

2.4. The IEEE 802.11ac

To perform the various downlink activity streams to different beneficiary STAs all the while, IEEE 802.11ac improves the MAC layer by proposing TXOP sharing. The thought of proposing TXOP sharing originates from the restrictions of the legacy EDCA TXOP rule. In EDCA when a station gets TXOP, frames of the same AC are transmitted. The fundamental thought of TXOP sharing is to permit the AP to perform simultaneous transmissions. With this plan, each EDCF of an AP utilizes its own particular EDCA parameters to get TXOP. At the point when an EDCF picks up a TXOP, it will be the proprietor of this TXOP, and its related ACs is considered as Primary AC and the leftovers ACs are the optional. Subsequently, the AP has two sorts of destinations: Primary and secondary destinations which are separately focused by information frames of essential AC and optional AC. 802.11ac adds new stage to ensure the TXOP sharing instrument. In this period, it is the Primary AC that chooses which secondary AC is allowed to share the TXOP to, and destinations to focus for transmissions. [6]

3. 802.11E MAC PARAMETERS AND THEIR CONTRIBUTION IN THE STARVATION

Many researchers have proposed various schemes to prevent the starvation of the lower priority queues. The schemes includes tuning mechanisms of CW, AIFS and TXOP dynamically, and investigating the impacts of the parameters. In [7] and [8], the authors proposed tuning mechanisms for CWmin and CWmax respectively, based on the collision rate. The collision rate is calculated at fixed intervals and results show that CWmin tuning mechanism given better throughput, medium utilization and delay when compared to the CWmax tuning with respect to the lower priority queues. The authors in [9] proposed a scheme to improve the QoS in IEEE 802.11e by introducing the Threshold-Based Admission Control and Contention-Window-Based Admission Control. In Threshold-Based Admission Control scheme each station needs to estimate the traffic condition. Depending on how the traffic condition is estimated and evaluated a call is admitted. The key idea of Contention-Window-Based Admission Control scheme is to adjust the CW values for different stations so that the lower priority queue is admitted even in the saturation conditions. A novel access method [10] is proposed to support absolute priorities in 802.11 and associated proportional throughput allocation for all the traffics. This scheme proposed a fair allocation of the priorities to all stations in the same class, fast adaptation to conditional changes. Dynamic tuning of the TXOP in EDCA parameters set[11] named DTXOP, is for adjusting TXOP depending on the current traffic statistics. This is aimed to prevent the starvation of BE and BK ACs with no degradation in QoS of the VO and VI real-time applications.

The dynamic tuning mechanisms are best fit to address the starvation, but the authors Johannes Zapotoczky and Katinka Wolter proposed a priority shifting mechanism to change the traffic priorities in a comfortable way. If there is no highest priority class in the network all lower priority classes can be shifted up to reduce the waiting time of the lower priority queues in the contention system. Xiao [12] proposed a model to the prioritized schemes provided by 802.11e by introducing more ACs with unique parameters set, such as the minimum and maximum contention window. This model has given better performance for all the traffics. TXOP limit adjusting mechanism proposed in [13] contributes to the performance improvement of the throughput and delay for the BE and BK traffics. This scheme involves the burst size distribution of TXOP limit. However the large TXOP allocations improves medium utilization and extends the stabilization of the network, but causes serious unfairness and security threats. This paper concludes that the TXOP limit can play an important role in the avoidance of starvation of the lower priority classes. The analytical model in [14] demonstrates the interaction between the TXOP and AIFS, CW. This model discusses the stability points of the all traffics and their dependency on TXOPlimit. In the Saturation conditions TXOP is crucial for the BE and BK traffics. This scheme improves the performance by separating the stable points slightly of all traffics. In paper [15], authors proposed a delay-aware distributed dynamic adaptation of contention window scheme (D2D), to improve the throughput and the channel access delay for the lower priority traffics. This scheme helps the lower priority queues to come out from the starvation whenever the delay is increased. The D2D scheme uses delay deviation ratio and channel busyness ratio to estimate the delay level and channel congestion status of the network. The authors in [16] investigated the effects of the offered load parameters on the network performance and saturation and non-saturation ranges of IEEE 802.11e EDCA. They show interaction of offered load and MAC parameters. The results show the appropriate network parameters and their impacts to preserve the network stability. [17]

4. ANALYSIS AND FUTURE DIRECTIONS

The IEEE task group 802.11 has been continuously enhancing the standards since 1999 as its first release appeared in the same year. Almost 20 amendments have been made to legacy standards which focus on to provide the best QoS for the real time applications. According to the privileges of the multimedia applications and its demand the most of the standards were concentrated on the preserving the QoS for them. The applications like web browsing, emails and telemetry are the basic applications. They should not be undermined due to their fundamental Internet use and business communications. The basic IEEE 802.11 has not considered any QoS aspects and it was working based on the RTS/CTS mechanism. It treats all traffics with same priority. The Task group enhanced the 802.11 to support QoS for the time sensitive applications and made 802.11e. This Protocol uses four ACs as discussed earlier and each AC holds unique type of traffic. Among all ACs the BE and BK can serve the fundamental applications but those ACs are starved by the other two if the network is saturated.

Many researchers have made studies on the starvation and proposed different approaches to solve the starvation problem. From the wide literature survey we come to know that MAC parameters have significant role in the starvation. The MAC Parameters CW, AIFS and TXOP are crucial and one more parameter Persistent factor is impressed but not significant. The significant parameters are to be managed in suitable way to improve the throughput of the lower priority queues since they are static in nature. The major challenge to the researchers is improving the QoS aspect for BE and BK with no ignorance of the QoS aspect of the VO and VI. The CW, AIFS and TXOP are to be tuned to achieve the QoS for BE and BK. In many schemes CW is tuned dynamically to achieve better performance. The contention window is maintained between CWmin and CWmax. The boundaries of the CW affect Twait value. Low Twait value AC will get transmit first. The CWmin and CWmax are to be managed dynamically. Some schemes prove that that CWmin is more important than CWmax while adapting dynamically. They calculated throughput by tuning CWmin and CWmax individually and observed that the CWmin gives better throughput than CWmax. While adapting the CW dynamically, some schemes were faced the problems with CTS and ACK time out events. This causes the performance degradation of the network. The contention window is managed with respect to the collision rate and delay analysis. A few schemes concentrated on AIFS tuning as it was also crucial in the calculation of the Twait. As shown in Table 4 the AIFS values are constant and helps the VO and VI to win TXOP every time. In paper [12] proposed a scheme to change the AIFS dynamically to help the lower priority queues from the starvation. This is also depended on the collision rate, delay analysis, network traffic condition, etc.

Table 3
Relation between MAC Parameters and QoS parameters

QoS Parameter *MAC Parameter*	*Throughput*	*Delay*	*Jitter*	*Latency*
CWmin	Significant	Significant	Significant	Significant
CWmax	Significant	Impressed	Impressed	–
AIFS	Impressed	Impressed	–	–
TXOP	Significant	Significant	Significant	Impressed
TXOP Aggregation	Significant	Significant	Significant	Impressed

In papers [13][14] authors concentrated on the TXOP limit. The TXOP limit helps the BE and BK to avoid starvation. The authors analyzed the impact of TXOP allocation and TXOP limit for all the ACs. These papers stated some fair TXOP allocation methods for the ACs and suffered from the security threats since long TXOPlimit is vulnerable to the Denial of Service Attacks. Table 3 shows that the role of MAC parameter to effect the QoS parameter in order to prevent the starvation of the lower priority queues. The parameters CWmin, CWmax, TXOP and TXOP aggregation played a vital role in the improvement of the throughput of the lowest precedence traffic. The same is represented in the table with the term" significant". The AIFS tuning mechanisms shows that AIFS parameter is playing major role but not significant role for the QoS aspect of the BE and BK. That is represented as "Impressed". Table 3 depicts relation between MAC parameters and QoS parameters. In Addition to the above tuning mechanisms few more schemes have been proposed to address the starvation. They include Priority shifting mechanism, bandwidth reservation for the BE and BK independently and TXOP aggregation mechanism. These schemes also have significant impact on the QoS parameters. The main reason for the starvation in IEEE 802.11e is static nature of the MAC layer parameters. In this work we considered the three most important MAC layer parameters of 802.11e, which are major contributors in the starvation of the lower priority AC's i.e., CW, AIFS, and TXOP.

Contention window and AIFS:

In order to decide which AC gets to transmit first the value Twait (AIFS + CWavg i.e., contention window average size) plays a major role. Low Twait AC transmits more number of times when compared to the larger Twait valued AC. It means that higher priority queue has lower Twait value. If the network is overloaded, the backoff procedure of the lower priority AC is interrupted continuously, which causes the reduction in number of transmissions of the lower priority AC. The moment, number of transmissions of lower priority AC reaches zero, it is called as starvation. If it is possible to tune the Twait by controlling the CWavg or AIFS or both, the lower priority AC will get to transmit sometimes rather than zero. The static values of the CW and AIFS are shown in the Table 4.

TXOP

TXOP is defined by the maximum length and starting time of transmission. TXOPlimit is defined as the time required to transmit one RTS/CTS control frame along with data frames. Higher TXOP values are more beneficial for the higher priority classes and lower TXOP values ultimately leads to the starvation of lower priority ACs.

Table 4
Static CW, AIFS,TXOP values.

AC	CW_{min}	CW_{max}	AIFS	TXOP limit
VO	8	16	3	3.264(ms)
VI	16	32	3	6.016(ms)
BE	32	1024	4	0(only one MSDU)
BK	32	1024	8	0(only one MSDU)

As shown in the Table 4 VO and VI queues will get more TXOPlimit values but BE and BK queues have TXOPlimit equivalent to transmission of one MSDU. Most of the times, if the network is loaded with all traffics the queues VO and VI wins the TXOP due to their lower contention window and AIFS and stays for long time. If we can manage the TXOP then we can limit the starvation of the BE and BK.

5. CONCLUSION

QoS is to be provided for BE and BK in addition to the voice and video due to their importance in the crucial areas. The protocols designed to provide the QoS mainly aimed for voice and video. Lower level traffic is starved by voice and video because those mechanisms were concentrated in the provision of QoS for voice and video. The protocol 802.11e is basic mechanism for QoS and it is not concerned about starvation of lower priority queues. The main reason is static nature of parameter set of 802.11e. Solutions of starvation which includes CW tuning mechanisms, AIFS dynamic tuning mechanisms, TXOP allocation and TXOP limit management schemes and priority shifting algorithms are evaluated. The CW tuning mechanisms affect the performance of BE and BK more than other two mechanisms AIFS tuning and TXOP tuning. Additionally, TXOP allocation and TXOP limit dependent schemes are fair to BE and BK.

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