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COMBINATION OF ACCESS CATEGORIES AND FRAME AGGREGATION SCHEMES FOR BANDWIDTH EFFICIENCY OF VHT 802.11AC

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Abstract

One of the primary requirements of multimedia applications such as VoIP and video streaming is quality of service (QoS) in a reliable satisfactory level for their end-users. In order to achieve the QoS requirements, the VHT 802.11ac standard utilizes the EDCA channel access method with its different access categories. On the other hand, in an attempt to provide a high-speed link, the 802.11ac standard introduces different techniques including the frame aggregation. Thereby, the main concern is that while the frame aggregation methods and EDCA access categories each individually attempt to enhance the communication performance, can their combination also enhance the overall performance of the delay-sensitive multimedia applications. The main contribution of this work is to identify the consequence of this combination and determine any positive or negative effects. For this purpose, we develop a model called ACFA, which combines all different types of frame aggregation schemes with all EDCA QoS access categories correspondingly. The NS3 simulation tool is used to implement the model along with a variety of distinct scenarios and obtain the results. The findings determine the effects of the combination on the performance of the VoIP and video multimedia traffics, which are furthermore compared with the normal non-multimedia traffics. The results show that due to different requirements of voice and video contents, they achieve improvement over different aggregation mechanism.

Keywords: Access categories, Frame aggregation, QoS, VHT 802.11ac.

1. Introduction

The enhanced distribution coordinate access (EDCA) provides channel access with quality of service (QoS) requirements for the wireless clients [1, 2]. Meanwhile, to prioritize data and provide the required level of QoS, particularly for multimedia applications, the EDCA maps the traffics coming from the applications in the upper layers into four different QoS access categories (AC). These four ACs include AC-VO, AC-VI, AC-BE, and AC-BK for voice, video, best effort, and back of traffics, respectively [3, 4]. During the traffic mapping, the QoS is application-specific and the priority order from the highest to the lowest is AC-VO (access category of voice), AC-VI (access category of video), AC-BE (access category of best effort), and AC-BK (access category of background). In this way, the QoS of the packets generated by the multimedia applications, are guaranteed and these packets are treated differently with higher order than the normal traffics such as email or web browsing.

In addition to providing QoS [5], the current wireless standard, called very high throughput (VHT) 802.11ac [6], applies different methods to enhance the overall network speed and connectivity. To achieve these, the 802.11ac introduces a variety of different enhancement methods in different layers. One of the enhancements performed at the media access control (MAC) layer, is frame aggregation in which, several data frames are grouped into one large frame to reduce the number of header overheads that are added to each data frame. The 802.11ac standard includes two mainframe aggregation mechanisms, which are the MAC service data unit (A-MSDU) and MAC protocol data unit (A-MPDU) aggregation [7, 8]. The A-MSDU is the default aggregation method in which, several MSDUs coming from the upper layer, are grouped in MAC sublayer to form one large frame and then one single MAC header is added to this large frame. This eliminates the need for individual MAC headers for each MSDU and results in reducing the MAC sublayer overheads. In contrast, the A-MPDU aggregation method works on MPDUs. In this method, several MPDUs coming from the MAC sublayer, are grouped in the physical layer to form one large frame and then one single physical header is added to this large frame. Similarly, this method eliminates the need for individual physical headers for every single MPDU. Although the A-MSDU and A-MPDU are the two main aggregation methods, binding these two methods also is possible, which can be considered as the third frame aggregation method called two-level frame aggregation.

While the aim of EDCA is to prioritize the QoS-sensitive applications based on the ACs, the frame aggregation methods tend to decrease the header overheads [9]. On the other hand, due to inherent characteristics of real-time traffics as being delay-sensitive and also having higher precedence over the other normal traffics, the main concern is the interaction between different frame aggregation methods and the level of QoS provided for the access categories by EDCA. This concern arises two main questions answering of which, is our main objective. Thus, this work contributes to this direction as follows:

- The first contribution is to determine whether implementing the frame aggregation has any positive influences and is appropriate for real-time multimedia traffics over the very high throughput 802.11ac networks or no-aggregation would possibly lead to better performance.

- The second contribution is to determine that in case of using frame aggregation, which type of frame aggregation can provide better performance for multimedia traffics such as Voice over Internet Protocol (VoIP) and video streaming in VHT 802.11ac network.

For this purpose, this work uses the NS3 network simulator tool to design and implement a model called Access Categories Frame Aggregation (ACFA). The model is fully organized and covers a variety set of scenarios, which bind all the ACs in EDCA to all frame aggregation schemes and also with no-aggregation in the VHT 802.11ac.

The structure of this work is as follows. Section 2 reviews the related works. Section 3 presents the details regarding the design and implementation procedure of the model. Section 4 discusses the results and Section 5 concludes the work.

2. Related Works

The current works are mostly based on investigating the impact of different aggregation sizes in either the 802.11n or 802.11ac. Sharon and Alpert [10] investigated the impact of enabling and disabling the Request to Send (RTS) and Clear to Send (CTS) transmissions on maximum application rate while varying aggregation size in A-MPDU and two-level aggregation methods for different access categories.

The results show that as the size of MSDUs and the aggregation size (the number of MPDUs/MSDUs per PSDU) increase, the ratio between the PSDUs' transmission time and the RTS/CTS overhead increases as well. However, the A-MSDU and other performance metrics such as throughput, delay, and packet loss for further investigating the possible effects are not taken into consideration.

Based on studies by Jonsson et al. [11], the UDP protocol is used in NS3 to perform the scenarios and experiments. In one scenario, the authors investigated the effect of transmission range on throughput as the distance between the nodes increases with no frame aggregation. Then, in another scenario, the A-MPDU frame aggregation is used to investigate the impact on the throughput. The results show lower throughput when A-MPDU frame aggregation is not used. With A-MPDU, even the lower data rates will get some improvement, but with the higher data rates, the throughput highly increases close to the physical layer data rate. However, the access categories or other frame aggregation mechanisms are not investigated.

The impact of frame aggregation mechanisms for improving the overall throughput of 802.11ac networks using a custom-made simulator written in C++ is studied [12]. The A-MSDU, A-MPDU, and two-level aggregation mechanisms are investigated while varying the number of MSDUs and MPDUs in one A-MSDU and one A-MPDU, respectively. The results are compared in terms of throughput and show that frame aggregation mechanisms enhance MAC efficiency and bandwidth utilization as the aggregation size increases. However, the work is without regard to other performance metrics, access categories, and also no-aggregation in MAC layer. Bourawy and Alokap [13] and Sharon and Alpert [14] investigated the varying frame aggregation size to examine the corresponding impacts.

The NS3 is used to implement 802.11n and to compare the throughput and delay between the A-MPDU and A-MSDU for a single user and between two-level aggregation and no-aggregation [15]. The results show a close amount of delay for both A-MPDU and A-MSDU. The results also show that as the packet size increases, a two-level aggregation shows better throughput than no-aggregation. However, 802.11ac standard in not investigated while other performance metrics and access categories are not taken into consideration. Emmanuel et al. [16] and Barreira, and Ascenso [17] also investigated the 802.11n performance in the presence of A-MPDU and A-MSDU frame aggregation mechanisms over video streams.

The NS2 is used to investigate the quality of service achieved for video streaming by A-MPDU and A-MSDU aggregation mechanisms [16]. The results show that the aggregated throughput is higher for A-MPDU than A-MSDU for video streaming. The results also show that as the system load increases, A-MPDU shows a better performance than A-MSDU in terms of throughput and delay.

However, the 802.11ac and the corresponding access categories are not investigated. Barreira, Ascenso [17] mentioned that different sizes of A-MSDU aggregation are examined for video streaming in an 802.11n network. The results show that the average PSNR decreases when the size of A-MSDU aggregate frames increases. However, 802.11ac and access categories are not investigated. There are also other studies that investigate frame aggregation in 802.11n networks [18-21].

Based on the related works, the current studies are limited to investigate the impact of different frame aggregation sizes by varying the number of MSDUs in one A-MSDU frame or the number of MPDUs in one A-MPDU frame. Their main objective is to determine the optimal size of an aggregated frame to be transmitted. However, despite its importance, the combination and also the interaction between frame aggregation and access categories in EDCA for multimedia applications is not yet known and has not been addressed. Since, the real-time multimedia applications such as VoIP and Video streaming, are among the most widely used applications, it is essential to identify this interaction, which is the main objective of this work.

3. ACFA Model Implementation

As it mentioned earlier, the main objective of the access categories frame aggregation (ACFA) model is to determine whether binding the ACs with EDCA and various frame aggregation schemes can enhance the QoS of the real-time multimedia applications. In order to implement the ACFA, a topology shown in Fig. 1 is developed.

- The NS3 tool is used to develop this topology in a 36 m × 36 m indoor building with nine 12 m × 12 m rooms. In this topology, there are:
- Twelve VHT 802.11ac stations with enabled QoS (QSTA) located in the first room. The range of IP addresses for the QSTAs is from 192.168.1.3 to 192.168.1.14 with the corresponding flow IDs from 1 to 12.
- One VHT 802.11ac access point with enabled QoS (QAP) in the fourth room with IP address 192.168.1.2.

One VHT 802.11ac traffic source with enabled QoS (QServer) in the last room with IP address 192.168.1.1. It is capable of generating three different types of traffic including video, voice, and best effort thus, forming video server, voice server, and best-effort server, respectively.

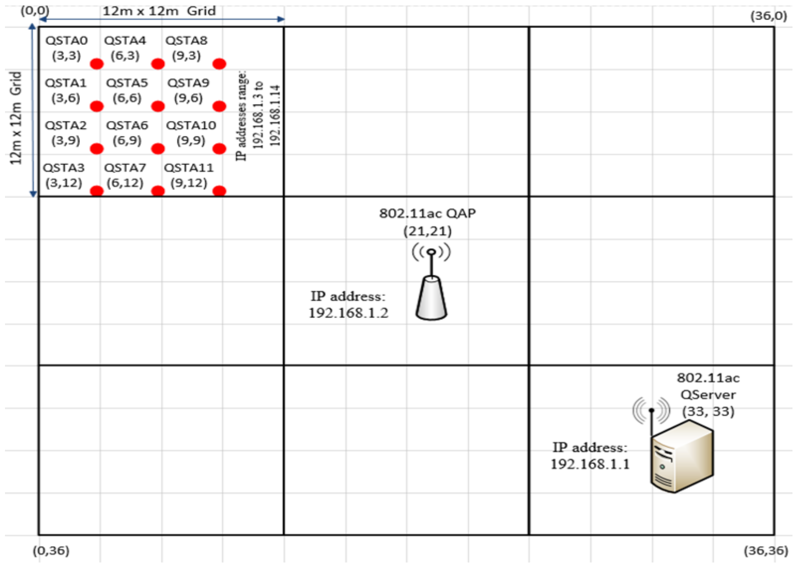

Fig. 1. Simulation network layout.

The QServer includes three different applications: two multimedia applications (App1 and App2) to generate voice and video packets and one UDP application (App3) to generate normal best effort packets. Each application sends 1000 bytes packets with 1Mbps transmission rate for 10 seconds simulation time.

As the packets are passed down to the IP layer, the packet classification is done by the ACFA model based on the type of service (ToS) field. Thus, based on the ToS, each packet enters into its own particular queue providing three different queues.

Then, the packets in each queue are passed down to the MAC sublayer to perform frame aggregation by the ACFA. This way, all the MSDUs in the same queue have the same QoS access category. Consequently, the voice MSDUs, for example, cannot be mixed with the best effort or video MSDUs inside the same aggregated frame.

In the MAC sublayer, the ACFA includes two different modes:

- Aggregation Mode (AM): in this mode, the ACFA model implements the three forms of aggregation, i.e., A-MSDU frame aggregation with 7935 bytes aggregated frame size, A-MPDU frame aggregation with 65535 bytes aggregated frame size, and two-level frame aggregations over every single queue.
- No-Aggregation Mode (NAM): in this mode, the ACFA model sends out the MSDUs in every single queue without any form of aggregation to be compared with the AM mode.

As a result, the ACFA model is performed four times over each queue resulting in 12 different implementation rounds. When the data is received by each QSTA, the performance metrics in terms of throughput, delay, packet loss, and jitter are measured during 10 seconds of simulation time per each flow. The implementation structure of the ACFA model is presented in Fig. 2.

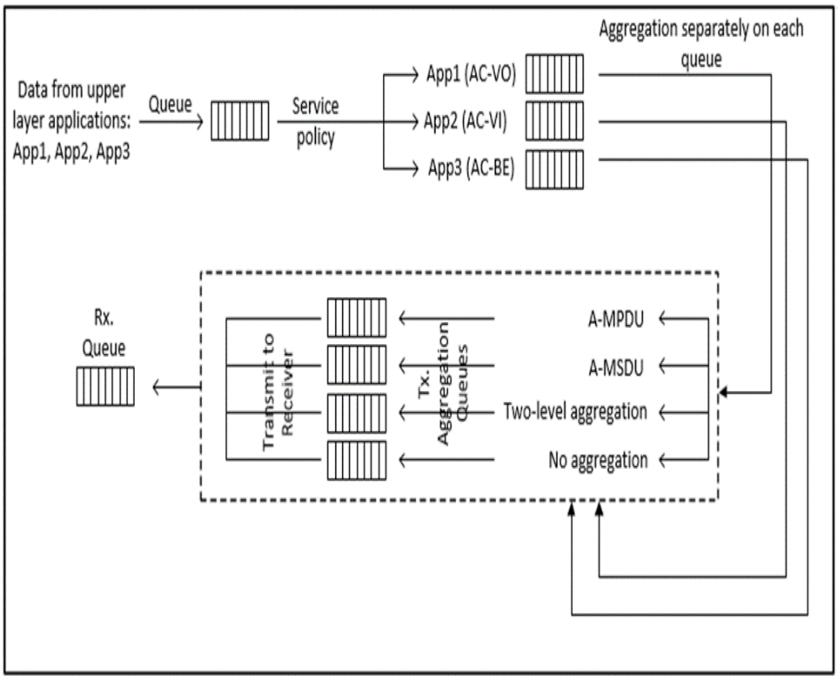

Fig. 2. ACFA model procedure.

The model further includes the following simulation parameters using NS3 commands:

- The maximum A-MSDU and A-MPDU sizes are set to 7935 and 65535, respectively according to the model requirements:

  MAC.SetType ("VO_MaxAmsduSize", UintegerValue (7935)).

  MAC.SetType ("VI_MaxAmsduSize", UintegerValue (7935)).

  MAC.SetType ("BE_MaxAmsduSize", UintegerValue (7935)).

  MAC.SetType ("VO_MaxAmpduSize", UintegerValue (65535)).

  MAC.SetType ("VI_MaxAmpduSize", UintegerValue (65535)).

  MAC.SetType ("BE_MaxAmpduSize", UintegerValue (65535)).

- The modulation coding scheme for 802.11ac is set to VhtMcs9:

  WIFI.SetRemoteStationManager("DataMode", StringValue("VhtMcs9")).

- The channel frequency is set to 40 MHz:

  PHY.Set (Phy/ChannelWidth", UintegerValue (40)).

- The QoS support is enabled for MAC layer of all 12 stations and AP:

MAC.SetType ("QosSupported", BooleanValue (true).

- The type of service (TOS) is set accordingly to prioritize traffics as AC_BE, AC_VO, and AC_VI with values of ox70, 0xc0, and oxb8, respectively:

  vector<uint8_t> tosValues = {0x70, 0xc0, 0xb8}.

  sinkSocket.SetTos (tosValue).

The simulation parameters are summarized in Table 1.

Table 1. Simulation parameters.

Parameter	Value
Data mode	VhtMcs9
Channel bandwidth	40 MHz
Frame aggregation methods	A-MSDU A-MPDU Two-level No-aggregation
Access category	AC-VO: highest priority AC-VI: high priority AC-BE: lowest priority
Maximum A-MSDU size	7935 bytes
Maximum A-MPDU size	65535 bytes
Number of 802.11ac stations with QoS support	12 QSTA (12 single flows)
Number of 802.11ac access points with QoS support	1 QAP
802.11ac traffic source applications	1 voice QServer 1 video QServer 1 best effort QServer
Data rate	1Mbps

4. ACFA Evaluation

In response to the two main questions in this work, the ACFA model is implemented to bind the voice, video, and best-effort access categories to A-MSDU, A-MPDU, two-level, and no-aggregation schemes.

The results are collected to quantify the corresponding influences and compare the possible similarities and differences in terms of throughput, loss ratio, delay, and jitter. The results from the implementation of the ACFA model are discussed in detail in the following subsections.

4.1. Voice access category

The traffics generated by the voice multimedia application integrated into the QServer, is the first access category to bind to the A-MSDU, A-MPDU, two-level, and no-aggregation schemes by the ACFA model in this section.

4.1.1. AC-VO throughput

This scenario is carried out to measure any influence of binding the A-MSDU, A-MPDU, two-level, and no-aggregation schemes to VoIP traffic on the throughput achieved by 12 QSTAs. The results are presented in Fig. 3.

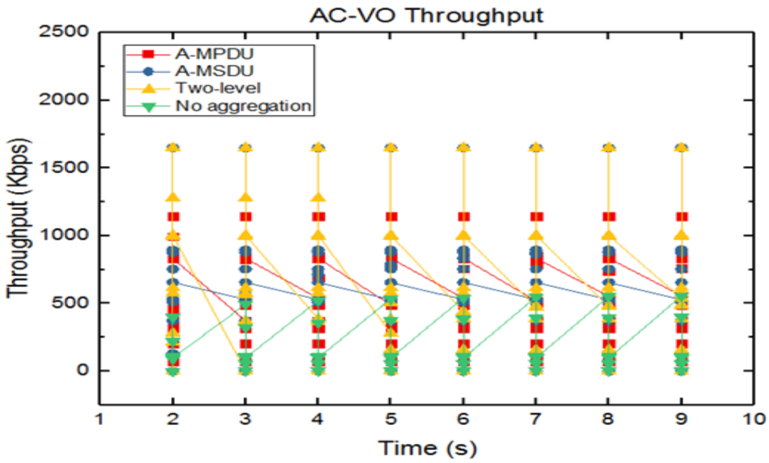

Fig. 3. Per-flow AC-VO throughput.

As the results show, when the voice packets are transmitted, the A-MSDU scheme provides higher throughput than the A-MPDU and two-level frame aggregation schemes. Furthermore, comparing the A-MPDU and two-level aggregation shows that while the two-level aggregation can provide better throughput than the A-MPDU, the difference is not considerable. Additionally, when the frame aggregation is not used during the VoIP communication, the end-users experience poor performance by the means of the least amount of throughput. Therefore, from the results, it is concluded that VoIP has the best QoS in terms of higher throughput when A-MSDU aggregation is used in 802.11ac.

4.1.2. AC-VO loss ratio

The main purpose of this experiment is to assess any possible changes in the number of lost VoIP packets when binding the AM mode and NAM mode to the voice packets. The loss ratio results obtained from the implementation of the ACFA model are presented in Fig. 4.

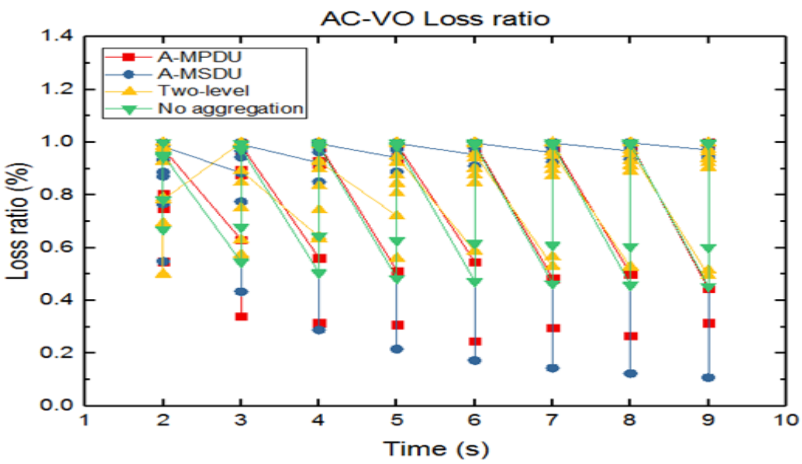

Fig. 4. Per-flow AC-VO loss ratio.

These results reveal that there are no significant differences in the number of lost packets between the AM mode and NAM mode, which in either case is below 1%. In the AM mode, the average loss ratio for A-MPDU and two-level aggregation similarly is about 0.89%. In contrast, the value reaches to about 0.91% for A-MSDU, which is equal to the amount of loss ratio in NAM mode when no frame aggregation is used. Therefore, during voice communication, having enabled or disabled frame aggregation does not have a considerable impact on the number of lost packets. Therefore, from the results it is concluded that to avoid VoIP quality degradation, A-MSDU is most efficient aggregation method in 802.11ac networks.

4.1.3. AC-VO delay

The ACFA model is further implemented to measure the delay of the voice packets in both AM and NAM modes. The results are presented in Fig. 5.

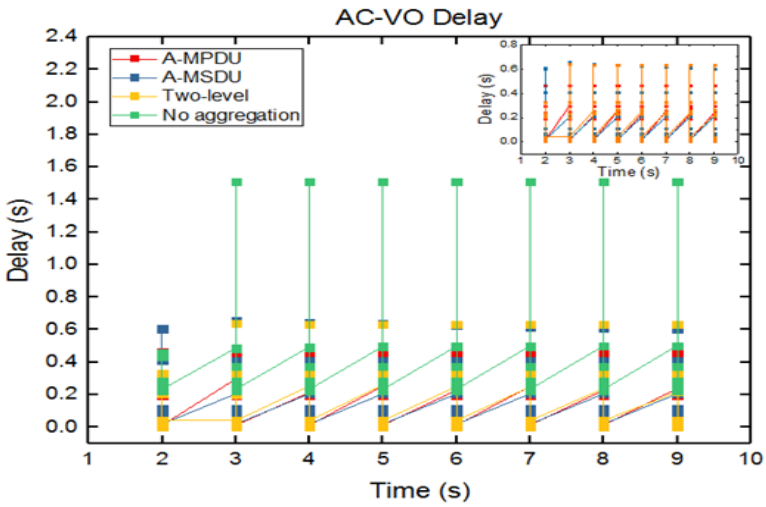

Fig. 5. Per-flow AC-VO delay.

Based on the results, we observe a very high amount of delay in NAM mode when no-aggregation is used over the voice packets. This very high value of delay results in poor voice quality for the VoIP end-users. In contrast, the delay is almost half in AM mode while there are no considerable differences in the amount of delay between A-MSDU, A-MPDU, and two-level aggregation schemes.

Therefore, performing any form of frame aggregation, either A-MSDU, A-MPDU, or two-level aggregation, over the voice packets results in better performance than NAM in terms of lower delay. Thereby, on the basis of the above results we conclude that to have a better VoIP quality, despite slight differences, A-MSDU and two-level aggregation methods are highly efficient.

4.1.4. AC-VO jitter

In order to evaluate the impact of binding the AM mode and NAM mode to the voice packets on jitter, the model is implemented and the results are obtained as shown in Fig. 6.

As it can be seen from this figure, the highest jitter belongs to NAM mode when the voice packets are transmitted with no-aggregation. Then, the jitter values in AM mode have the same ranges for all three frame aggregation schemes, which confirm the delay results. Thus, for VoIP applications, any type of frame aggregation can enhance voice efficiency in terms of lower jitter. The results reach the conclusion that using A-MSDU and two-level aggregation methods in 802.11ac networks provides better VoIP quality for the end-users. For better visualization, the average of the AC-VO results is summarized in Fig. 7.

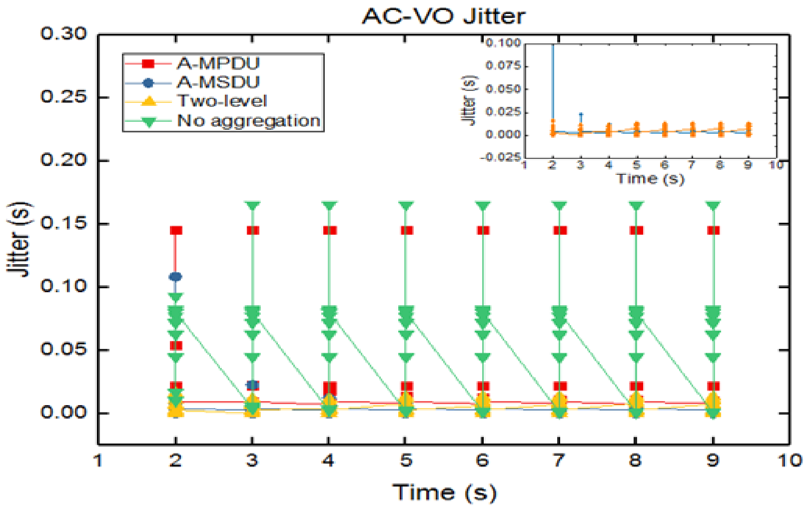

Fig. 6. Per-flow AC-VO jitter.

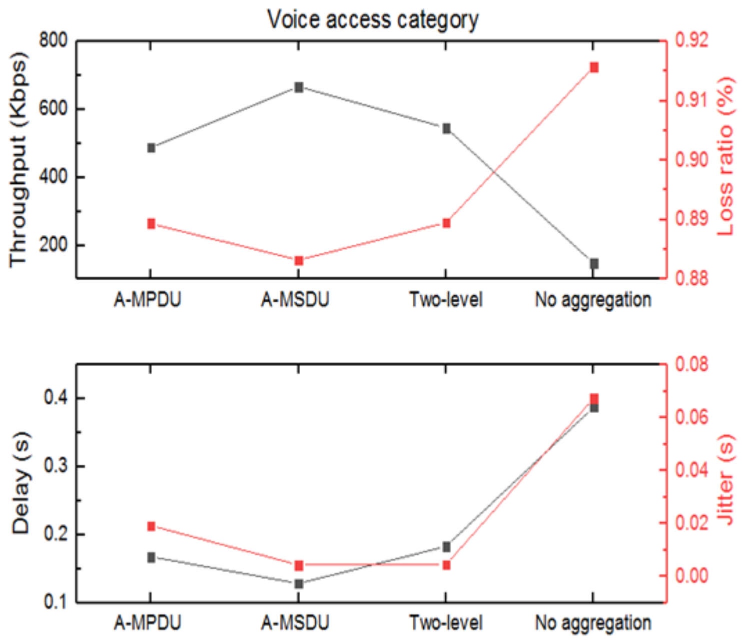

Fig. 7. Average AC-VO comparison.

4.2. Video access category

Further tests are carried out by the experiments in this sub-section to perform video streaming using the QServer in the ACFA model. The video packets in the MAC layer go under two modes. In the AM mode, A-MSDU, A-MPDU, and two-level frame aggregation methods are performed over the video packets and the results are determined. Then, in the NAM mode, the video packets are transmitted without involving any frame aggregation mechanisms and the results are obtained to be compared with the results in the AM mode. The video results are presented in this subsection.

4.2.1. AC-VI throughput

This experiment takes into account the video packets and attempts to measure the impact of performing aggregation methods in AM mode and no-aggregation in NAM mode over the video packets. The throughput results of the video packets transmitted from the QServer to 12 VHT end-users are presented in Fig. 8.

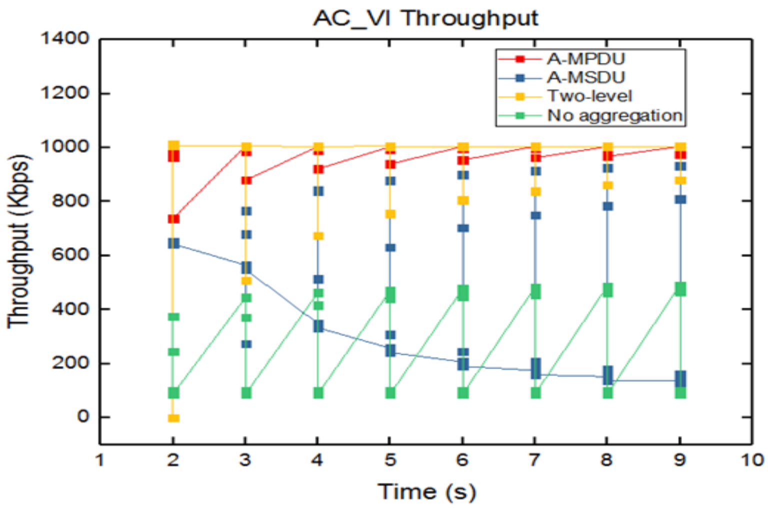

Fig. 8. Per-flow AC-VI throughput.

The results imply in the AM mode that the amount of throughput for the video packets in the A-MSDU scheme is identical to the voice packets (about 700 Kbps). Therefore, regardless of being in voice or video access categories, the A-MSDU achieves the same throughput for these two ACs.

However, the video findings show different behaviour for A-MPDU and two-level aggregation schemes over the video packets compared to the voice packets. While the throughput of the voice packets was lower when binding to the A-MPDU and two-level aggregation schemes, the throughput of the video packets is much higher when using these two schemes. In this case, the throughput reaches to about 1000 Kbps for video packets while it is about half of this value (500 Kbps) for the voice packets.

On the other hand, in NAM mode, the results of the voice and video ACs are the same, which is much lower than in the AM mode. Thus, the findings reveal that like voice packets, binding any type of frame aggregation scheme, either A-MSDU, A-MPDU, or two-level, to the video packets can improve the overall performance of the 802.11ac networks in terms of higher throughput. In this regard, while the A-MSDU frame aggregation scheme is suitable for the voice packets, the A-MPDU and two-level aggregation are better aggregation schemes for the video packets when higher throughput is the main concern.

4.2.2. AC-VI loss ratio

The main objective of this experiment is to measure the number of lost packets when binding of the video packets is done in the AM and NAM modes. The loss ratio results are presented in Fig. 9.

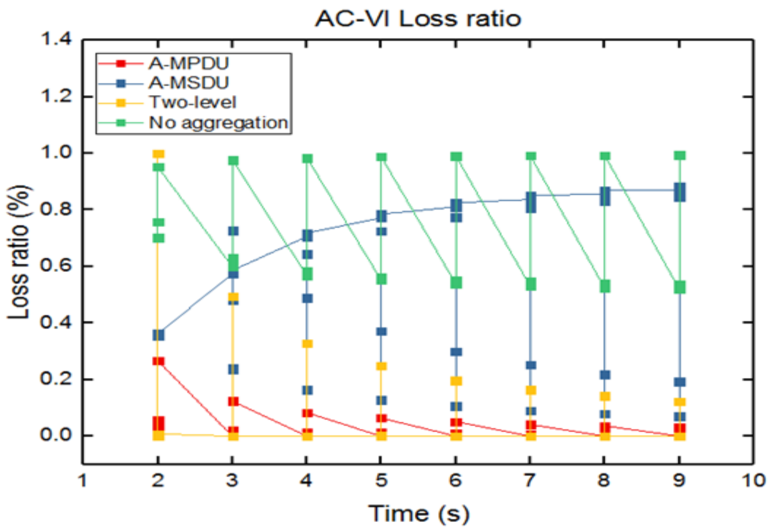

Fig. 9. Per-flow AC-VI loss ratio.

The loss ratio findings confirm the throughput results of the video packets. Based on the above results, both video and voice ACs highly suffer from the highest amount of lost packets in the NAM mode when no-aggregation is used in video communications. In contrast, the number of lost packets is much lower when any type of aggregation schemes is performed.

In this case, while the least amount of lost packets for the VoIP applications is achieved when A-MSDU is used, for video streaming applications, the A-MPDU and two-level aggregation schemes provide the least number of lost packets. Therefore, binding the video packets to A-MPDU and two-level aggregation schemes can provide better performance by the video streaming applications in terms of the very low loss ratio.

4.2.3. AC-VI delay

This experiment is conducted in an attempt to observe the impact of video access category binding to the AM and NAM modes on the end-to-end delay of the video packets. The delay results of the video access category are provided in Fig. 10.

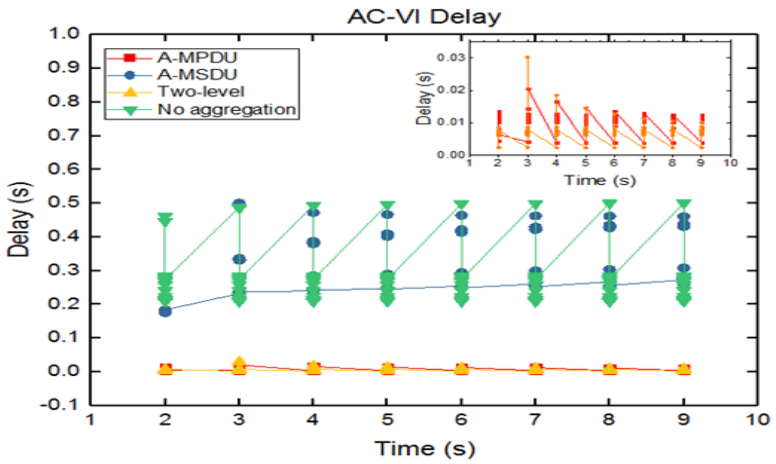

Fig. 10. Per-flow AC-VI delay.

The findings indicate that the highest delay in the 802.11ac network happens when either A-MSDU frame aggregation or no-aggregation are used over the video access category. In contrast, applying the A-MPDU or two-level aggregation schemes can enhance video performance in terms of very low delay. Observing the different behaviour when comparing the video delay results with the voice delay results prove the importance of binding of which, access category to which, frame aggregation mechanism. As the results show while binding the voice AC to A-MSDU can enhance the performance of VoIP applications in terms of lower delay, the A-MPDU and two-level frame aggregations are better choices for video applications in the VHT 802.11ac networks.

4.2.4. AC-VI jitter

This experiment provides insight into the delay variations by demonstrating the outcomes when binding the video AC to the frame aggregation schemes in the AM mode and also in the NAM mode. The results are provided in Fig. 11.

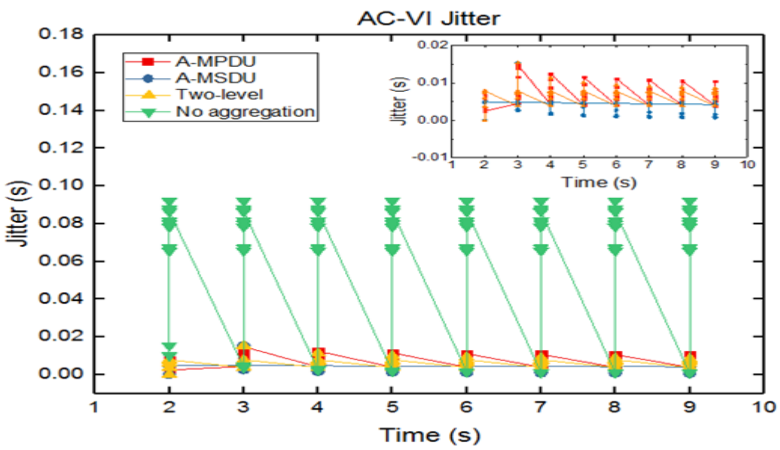

Fig. 11. Per-flow AC-VI jitter.

The above results provide evidence that the highest jitter occurs in the NAM mode resulting in poor video streaming. In contrast, the three frame aggregation schemes in the AM mode almost present the same amount of jitter. Additionally, comparing jitter values of the voice AC and video AC indicates that the voice packets have higher jitter than the video packets in the AM mode. A summary of the video streaming results is provided in Fig. 12.

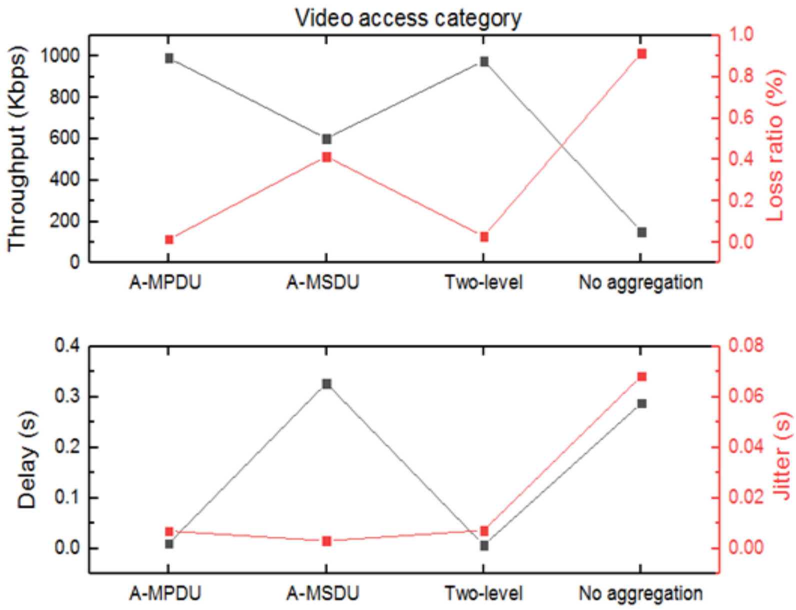

Fig. 12. Average AC-VI comparison.

4.3. Best effort access category

The above experiments bind the access categories related to the real-time multimedia applications in the AM and NAM modes. In contrasts, the experiments in this sub-section involve binding of the normal traffic (best effort) to the AM and NAM modes. The results are measured and utilized to be compared with the multimedia access categories.

4.3.1. AC-BE throughput

This experiment attempts to point out the effects of the AM and NAM modes on throughput performance of the best effort (normal) traffic. The results are measured to be compared with the multimedia access categories. The throughput results of the best effort AC are demonstrated in Fig. 13.

The results imply the significance of the high impact of performing any type of frame aggregation schemes over the BE traffics. While the least amount of throughput belongs to the BE packets in NAM mode, the AM mode provides the highest amount of throughput. Regardless of binding the A-MSDU, A-MPDU, or two-level frame aggregation schemes to the BE traffics, all of them provide almost the same throughput values, which are significantly higher than the NAM mode. Thus, despite the tight correlation between the high performance of the multimedia applications and the type of the frame aggregation scheme, the difference between the type of the schemes is not considered for the best effort traffics. As a result, when the best effort traffics are exchanged in the 802.11ac networks, the type of aggregation scheme is not important as all the three schemes provide identical throughput.

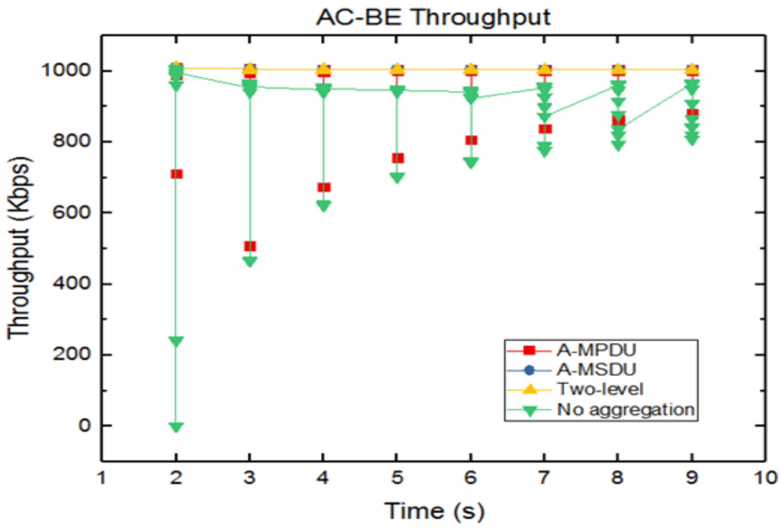

Fig. 13. Per-flow AC-BE throughput.

4.3.2. AC-BE loss ratio

This experiment is carried out to measure the number of lost packets belong to the BE access category in both AM and NAM modes. The results are illustrated in Fig. 14.

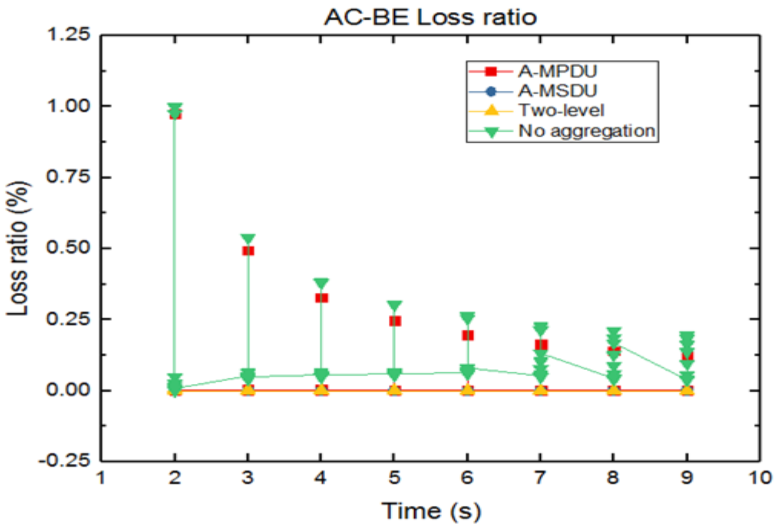

Fig. 14. Per-flow AC-BE loss ratio.

As the results suggest, when the A-MSDU, A-MPDU, or two-level frame aggregations mechanisms are bound to the best effort traffics, the number of lost packets significantly decreases compared to when no frame aggregation is used. On the other hands, there are no considerable differences between the number of lost packets caused by each frame aggregation scheme in the AM mode while the number is a bit higher for the A-MPDU than the other two schemes.

4.3.3. AC-BE delay

The primary aim of the present experiment is to examine whether changing the AC from the multimedia to the best effort will influence the amount of delay in AM and NAM modes. The results are gathered and presented in Fig. 15.

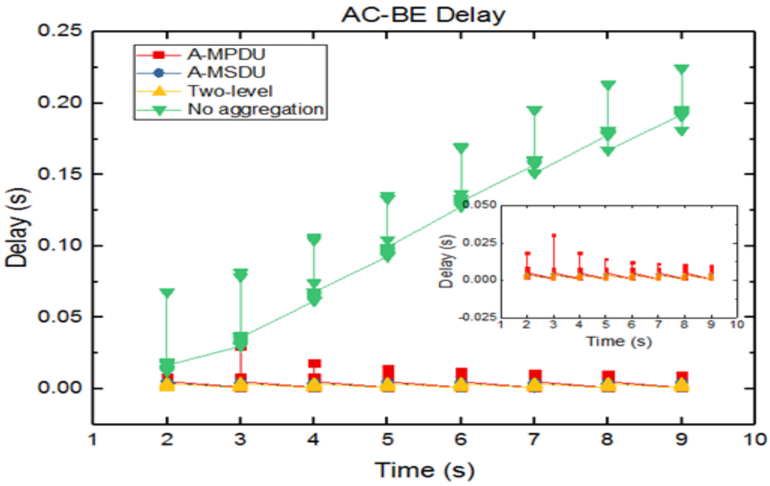

Fig. 15. Per-flow AC-BE delay.

The results prove the significant importance of having enabled frame aggregation mechanism for delay reduction of the normal traffics exchanged in the 802.11ac networks. In the NAM mode, the packets in the best effort access category experience very large end-to-end delay. In contrast, when these packets are exchanged in the AM mode, the delay is very low with very small differences between the three frame aggregation schemes. Thus, when the best effort packets are transmitted in the VHT 802.11ac networks, enabling any type of frame aggregation schemes, regardless of the type of scheme, can highly improve the packets delay.

4.3.4. AC-BE jitter

In order to determine the amount of jitter that the best effort packets will experience in AM and NAM modes, the normal UDP packets (BE) are utilized in this experiment. The results are presented in Fig. 16. The above findings reveal the same behaviour of the delay and jitter in both AM and NAM modes for the best effort AC packets. Again, the BE packets in NAM mode experience the highest hitter in comparison with much lower jitter in the AM mode. The summary results of binding the best effort AC to the frame aggregation schemes in the AM and NAM modes is provided in Fig. 17.

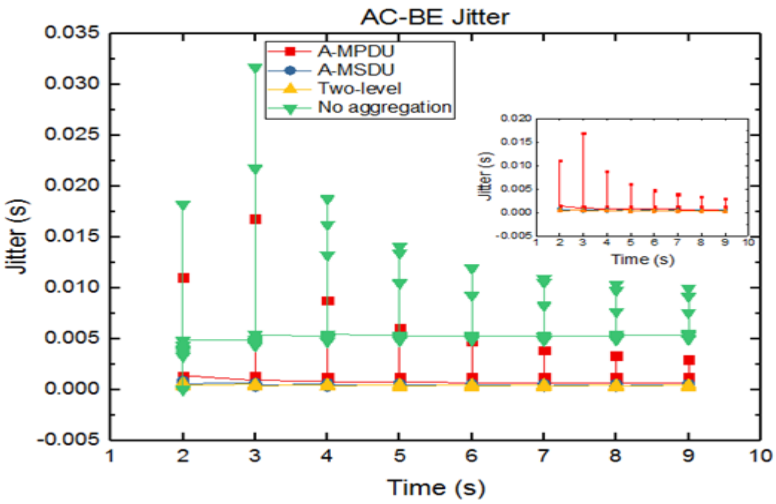

Fig. 16. Per flow AC-BE jitter.

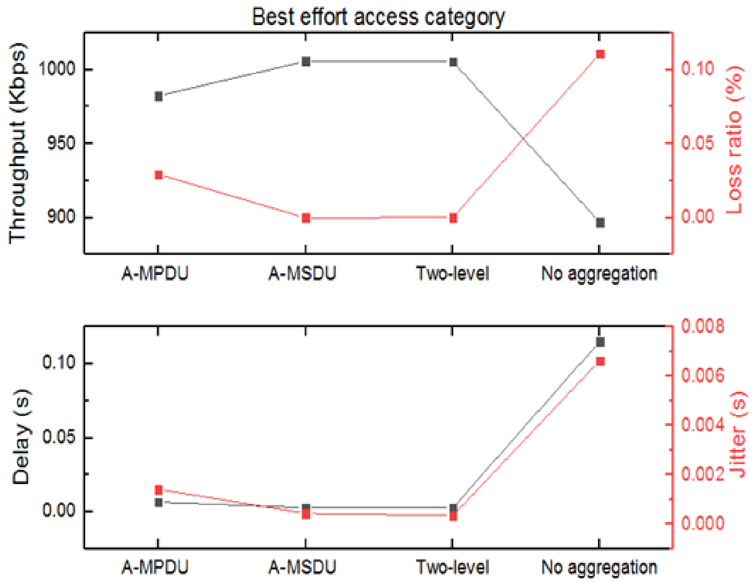

Fig. 17. Average AC-BE comparison.

5. Conclusion

The present work attempts to combine the three frame aggregation methods and also no-aggregation with the three EDCA access categories including voice, video, and best effort. In order to achieve this, a model called ACFA is designed and implemented in NS3 network simulator tool. The implementation results prove some similarities and some significant differences between the multimedia ACs and the best effort AC. In all ACs, the NAM mode provides significant poor performance for the 802.11ac networks in terms of low throughput and high delay, packet loss, and jitter. On the other hand, the results are different for multimedia

ACs and best effort AC in the AM mode. Based on the results, for voice applications, the A-MSDU frame aggregation provides better performance than A-MPDU and two-level frame aggregation mechanisms. The results prove different behaviour for video applications. For the video AC, the A-MPDU and two-level frame aggregation methods provide much better performance than the A-MSDU scheme. Furthermore, when it comes to non-multimedia applications (the best effort AC), there is no significant difference between the performance of the A-MSDU, A-MPDU, or two-level frame aggregation mechanisms and all of them provide an almost identical level of performance in the VHT 802.11ac networks. Based on the findings, it is concluded that to experience the optimal performance of the real-time services such as voice and video by the end-users of such services, performing the A-MSDU over voice packets and A-MPUD over the video packets will meet the required QoS expectations. In this work, the performance of 802.11ac is determined in the combination of access categories and aggregation mechanisms. Future research should consider the potential effects on 802.11ax as the future successor of 802.11ac.

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