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AN EFFICIENT IMPROVEMENT OF FRAME AGGREGATION MECHANISMS FOR VHT AT MAC AND PHY LAYERS IN IEEE802.11AC USING MIMO CHANNEL

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ABSTRACT

This paper presents and investigates the amendments of WLAN on physical and MAC layers, which can help the IEEE802.11ac to achieve the maximum data rate. The analytical model has been driven the normalized throughput. This work has discussed three aggregation techniques such as Aggregate MAC Protocol Data Unit (AMSDU), Aggregate MAC Service Data Unit (AMPDU), and the proposed combining technique of AMSDU and AMPDU is analyzed and illustrated. Our simulation model consider many technologies such as the modulation, coding, channel bounding, and spatial streams. The best results have been achieved with the hybrid technique of AMSDU/AMPDU in terms of MAC efficiency and the throughput. In case of QPSK with 40 MHz and 4-Spatial Streams (4-SSs), the highest improvement is recorded for AMSDU/AMPDU with increasing the throughput by 11.5 Mbps and improving the MAC efficiency around 14.38% compared with conventional aggregation techniques.

Keywords: *Frame aggregation, IEEE 802.11ac, MAC layer, Throughput, AMSDU and AMPDU.*

1. INTRODUCTION

IEEE 802.11ac is considered the newest standard of wireless LAN, which can support Very High Throughput (VHT) at 6 Gbps and upwards. The IEEE802.11ac has a significant enhancement on the performance with respect to the conventional 802.11 standards. The IEEE802.11ac realizes Very High Throughput (VHT) up to 6.933 Gbps and operates at 5 GHz unlicensed band [1]. Various amendments on the physical and MAC layers lead to achieve this amount of VHT.

At the PHY layer, higher order modulation technique (e.g. 256 QAM) is used in the IEEE802.11ac which in turn leads to raises the data rate up to 33% compared with 64 QAM used by IEEE802.11n standard [2]. Besides, efficient coding schemes with different code rate such as $\frac{1}{2}, \frac{2}{3}, \frac{3}{4}$, and $\frac{5}{6}$ are supported [3] [1]. These coding rates are consequently increased the data rate [1]. Also, there is a novel feature to be added to the IEEE802.11ac, which is called the channel bounding enables using the channel bandwidth up to 80 MHz while the maximum supported bandwidth with conventional versions is 40 MHz [4]. This increases the data rate up to 50 % [5]. Furthermore, an optional feature allows using wider channel bandwidth up to 160 MHz [6]. The number SSs are used in MIMO and OFDM increased from 4 in the legacy version to 8 in the IEEE802.11ac, which leads to increase the data rate as well [1], [7].

Many studies have been conducted on the MAC layer aggregation technique. The frame aggregation technique is considered the most significant factor in MAC layer that enhances the throughput. A such technique can increase the throughput and reduce the required time for accessing the users to the network and transmitting the preamble and header of frames. This can be done by aggregating the numbers of frames into a single frame [8]. This technique has been discussed by many authors. In Ref. [9], authors were proposed the algorithms to balance the tradeoff between the throughput and latency. Their results show that activate or deactivate the aggregation in which it is dynamically kept the latency for real time applications at minimum levels with minimum throughput effect. Eunbi et al., in Ref. [10], were discussed an algorithm to improve the throughput by selecting an optimal fragment length for the MPDU technique depends on various channel conditions, which was determined by client choice. As in Ref. [11] proposed an algorithm to identify optimal fragment length based on the time of MSDU technique. In Ref. [12], a hybrid aggregation algorithm is proposed. This enhances the throughput by providing the minimum frame error rate compared with MSDU aggregation. The validated of this algorithm is proved for multi users MIMO transmissions. For industrial Wi-Fi 802.11 devices, A new aggregate method has been suggested in Ref. [13] to improve the throughput by modifying both the upper and lower MAC sublayers.

This paper focuses on the frame aggregation techniques for IEEE802.11ac standard. A new aggregation technique has been proposed to improve the transmission efficiency and throughput. During investigating the performance of this technique, different features of PHY layer will be considered, which can affect the throughput levels such as the modulation, coding, channel bounding, and spatial stream.

The rest of paper structures as follows. Section 2 introduces the frame aggregation techniques. A mathematical model of proposed aggregation technique based on MAC and PHY layers discusses in Section 3. The simulation results present in Section 4. Section 5 summarizes the paper.

2. FRAME AGGREGATION OF IEEE 802.11AC

The pivotal techniques for MAC layer enhancement of IEEE802.11ac are AMPDU and AMSDU. The way of importing and exporting the data between the upper of MAC sublayer and the higher layers considers the key difference between AMSDU and AMPDU. The Aggregation algorithm uses these techniques performed by using single block of Acknowledgment (ACK) frame to exchange multiple MPDUs [14].

2.1 AMSDU

The efficiency of the MAC layer can be improved by using this aggregation algorithm through allows multiple MSDUs to be transmitted to the same destination in a single MPDU. The IEEE802.11ac supports the AMSDU algorithm is mandatory at the destination such as TCP acknowledgment. The AMSDU is designed to buffer the multiple received packets from the above layer of MAC layer. The process of AMSDU is finished after arrive buffering packets size to the maximum AMSDU threshold or when it is reached the maximum delay of buffering packets to a pre-defined value. The maximum size of conventional and High Throughput (HT) are either 3839 bytes or 7935 bytes, respectively, while for VHT there is no constraint on the maximum size of AMSDU [15]. The structure of AMSDU is shown in Figure 1. It is clearly seen that each arrived packet from the logical link control sublayer followed by 14 bytes of the source and destination addresses to form the subframe after adding padding from 0-3 bytes, where is useful to identify the beginning of the subframe at the receiver. The main problem of using AMSDU after compressing all subframe into a single MPDU is the noisy channel, where any subframe corrupted during the transmission leads to retransmit the entire size of AMSDU [14], [15].

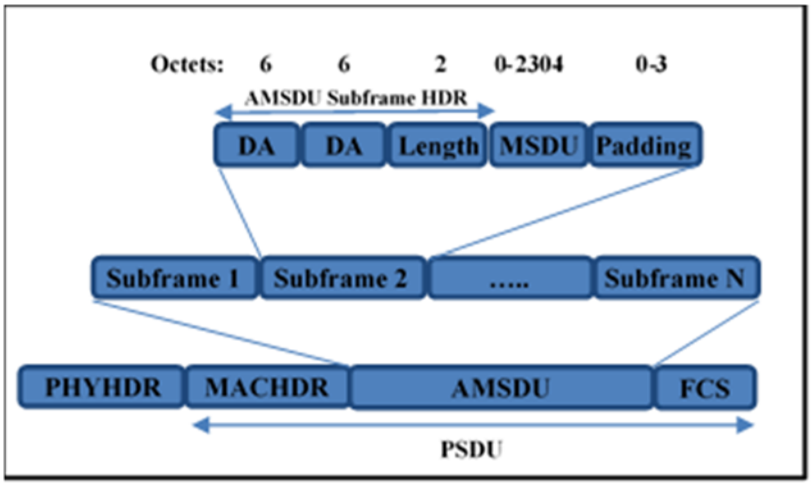

Figure 1: Basic structure of AMSDU subframe

2.2. AMPDU

In this algorithm multiple subframes (MPDU) joints with a single PHY header. The concept of AMPDU is the same used with AMSDU, the main difference is that AMPDU functions after the MAC header encapsulation process. Also, the AMSDU must matching aggregated frames with the traffic identifiers which is not necessary for AMPDU. In AMPDU, all subframe addresses to the same destination address. Consequently, the total numbers of aggregated subframes in AMPDU depends on the amount of queue transmission packets instead of holding time. The maximum size of AMPDU for HT and VHT are 65 535 bytes and 1048575 bytes, respectively [14]. There is further constrained of size AMPDU based on the capabilities of the destination. The extreme number of subframes that collected in AMPDU is 64 due to size acknowledgment bitmap is 128 bytes, each subframe mapped by two bytes. Lastly, 4095 bytes are limited length for each subframe, where the limited time of PHY Protocol Data Units (PDDU) must be less than 5.46 ms, this calculated from dividing the maximum length over lowest physical data rate [14], [15].

Figure 2 describes the structure of AMPDU. 4 bytes of set fields (delimiters) are added before each subframe, and the padding changes from 0-3 bytes inserted at the end. The primary function of delimiter header is to explain the location and length for each subframe inside AMPDU. The Cyclic Redundancy Check (CRC) byte used to check the authenticity of the previous bits. The padding field used to recognize the subframe at the destination while the delimiter signature assists the de-aggregation process.

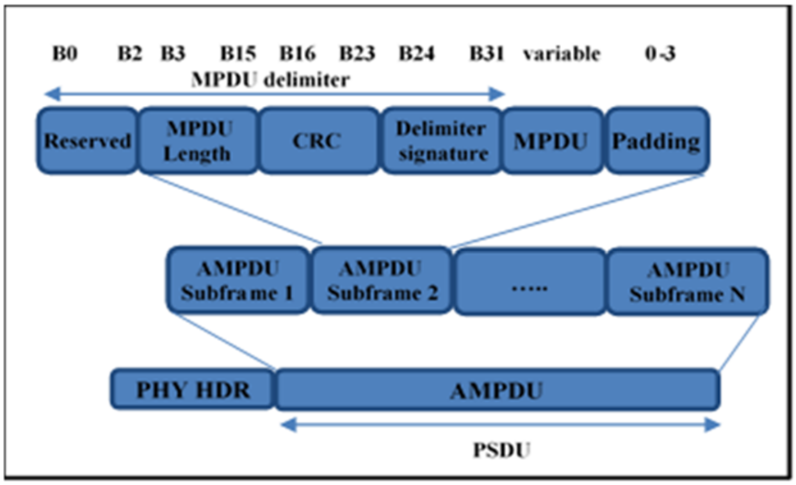

Figure 2:Basic structure of AMPDU subframe

2.3. Two-level aggregation

A new proposed aggregation scheme presented in Ref. [14] will be shown in this subsection after modified it concerning IEEE802.11ac standard to realize VHT. This scheme depends on a combination of AMSDU and AMPDU (AMSDU/AMPDU) over two levels. The principle and structure of this proposed scheme are described in Fig.3. At the first level, compacts all MSDUs which buffered in the AMSDU temporary storage area into a single AMSDU. If the traffic sent to different identifiers, then these frames transmitted to the second level for combining with any AMSDUs coming from the first level by using AMPDU aggregation. As it was mentioned above, the limited time of PPDU for AMPDU must be less than 5.46 ms, where MSDU or AMSDU will not be transmitted if the time exceeded this threshold.

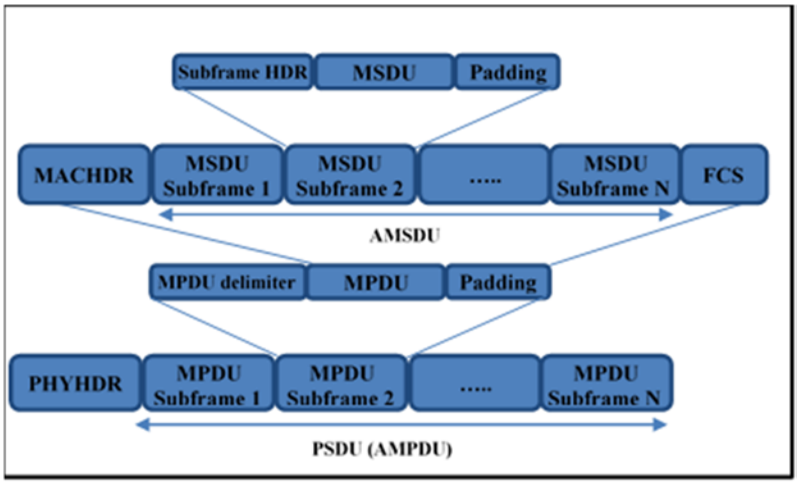

Figure 3: Basic structure of combination AMSDU/AMPDU subframe

3. ANALYTICAL MODEL for AMSDU/AMPDU

In this section, the theoretical formulation is derived to show how this synthesis is more efficient compared with using AMPDU and AMSDU aggregation alone. Our analysis model considers that there are *n* number of users connected via an access point (AP). All users can have the ability to sense the traffic sent from other ones and work in saturation mode. In the saturation mode, all users ready to transmit the packets to the AP at any time. The transmission process successes if the user receives an acknowledgment packet from the AP. Otherwise, the data must retransmit. If two or more stations access the medium at the same time, the collision happened, and the transmission failed.

Skordoulis et al., in Ref [14] introduces the Markov model to calculate the Distributed Coordination Function (DCF) throughput. The user behavior is described by two stochastic processes *i* and *j*, which are the backoff time stages and backoff time value, respectively. When the user transmits packet successfully, then $i = 0$ but if the user is sensing the medium and find it busy that leads to increasing *i* by one until reach the maximum backoff stage value (m). However, if the medium is busy and the collision happened, *j* is determined uniformly between [0, W_i−1] and decreases by one if the medium is an idle. Where, W_i is the contention window of the user at i_{th} backoff time, as demonstrated in Eq. (1).

$$W_i = 2^i W_{min} \qquad i\epsilon[0,m] \tag{1}$$

Through the arbitrarily selected slot, the channel activity can be described by two states as follows:

1. Idle (no transmission from any user)
2. Busy due to collision or successful transmission.

For randomly selected time slot, the user tries to transmit the packet with probability τ. When two or more users access to the channel at the same time resulting the collision, and that leads to duplicate the W_i based on the binary exponential backoff mechanism. For saturation behavior, τ is calculated depends on the stationary probability $b_{i,k}$ [2]:

$$b_{0,0} = \frac{2(1-2p)(1-p)}{(1-2p)(W+1)+pW(1-(2p)^m)} \tag{2}$$

$$\tau = \sum_{i=0}^{m} b_{i,0} = \sum_{i=0}^{m} p^i b_{0,0} \tag{3}$$

$$\tau = b_{0,0} \cdot \frac{(1-p^{m+1})}{(1-p)} \tag{4}$$

It depends on the collision probability, as shown in Eq. (5).

$$p = 1 - (1-\tau)^{n-1} \tag{5}$$

The throughput (S) is defined as the ratio of successful transmitted data in the slot per time of a slot, calculated by:

$$S = \frac{P_{tr} P_S N_A E[L]}{E[T]} \quad (6)$$

where, P_{tr} is the probabilty of one or more transmisiom in chosen slot time and P_s denotes the probability of successful transmission.

$$P_{tr} = 1 - (1 - \tau)^n \quad (7)$$

$$P_s = \frac{(n\tau)(1 - \tau)^{(n-1)}}{P_{tr}} \quad (8)$$

where, $E[L]$ is the average size of payload data.

$$N_A = \begin{Bmatrix} N_{AMSDU} & AMSDU \\ N_{AMPDU} & AMPDU \\ N_{A_{MSDU}} . N_{A_{MPDU}} & AMSDU/AMPDU \end{Bmatrix} \quad (9)$$

The duration time of slot *E[T]* is calculated as depicted in Eq. (10).

$$E[T] = \sum_{\forall t,T} T f_T(t) \quad (10)$$

$$T = \begin{Bmatrix} \sigma & if\ the\ channel\ is\ idle \\ T_s & if\ successful\ transmision \\ T_c & if\ collision\ occurs \end{Bmatrix} \quad (11)$$

where,
σ : *emptyslot time* duration.
T_s, T_c : *avarge time of successful and unsuccessful transmision.*

The corresponding probability ($f_T(t)$) of the above parameters is calculated as visualized in Eq. (12).

$$f_T(t) = \begin{Bmatrix} 1 - P_{tr} & if\ T = \sigma \\ P_{tr} P_s & if\ T = T_s \\ P_{tr}(1 - P_s) & if\ T = T_c \end{Bmatrix} \quad (12)$$

From Eq. (6) and Eq. (10), S can be calculated. As aforementioned in the previous sections, IEEE 802.11ac achieves the VHT due to the enhancement in PHY and MAC layers (efficient coding, higher order modulation technique, channel bounding, increases the number of spatial streams, and the frame aggregation). So, in order to calculate T_s ,T_c, the presented model in Ref. [14] must be modified by taking into account these features. The frame format of VHT at the PHY layer for IEEE802.11ac is illustrated in Figure 4. Assume that T_{PH} is the transmission time of the user.

$$T_{PH} = T_{LEG-PREAMBLE} + T_{L-SIG} + T_{VHT-SIG-A} + T_{VHT-PREAMBLE} + T_{VHT-SIG-B} + T_{DATA} \quad (13)$$

$$T_{LEG-PREAMBLE} = T_{L-STF} + T_{L-LTF} \quad (14)$$

$$T_{VHT-PREAMBLE} = T_{VHT\_STF} + N_{VHTLTF}\ x\ T_{VHT\_LTF} \quad (15)$$

The values of the parameters (T_{L-SIG}, $T_{VHT-SIG-A}$, $T_{VHT-SIG-B}$, T_{L-STF}, T_{L-LTF}, T_{VHT_STF}, N_{VHTLTF}, and T_{VHT_LTF}) are shown in Figure 4. Similarly,

$$T_{DATA} = \begin{Bmatrix} N_{SYM} \times T_{SYM} & for\ long\ GI \\ T_{SYML} \left\lceil \frac{T_{SYMS} \times N_{SYM}}{T_{SYML}} \right\rceil & for\ short\ GI \end{Bmatrix} \quad (16)$$

The values of Guard Interval (GI), symbol interval (T_{SYM}), Short GI symbol (T_{SYMS}), Long GI symbol (T_{SYML}) are summarized in Table 1.

$$T_{SYM} = \begin{Bmatrix} T_{SYML} & for\ long\ GI \\ T_{SYMS} & for\ short\ GI \end{Bmatrix} \quad (16)$$

$$N_{SYM} = m_{STBC} \times \left\lceil \frac{M}{m_{STBC} \times N_{DBPSL}} \right\rceil \quad (17)$$

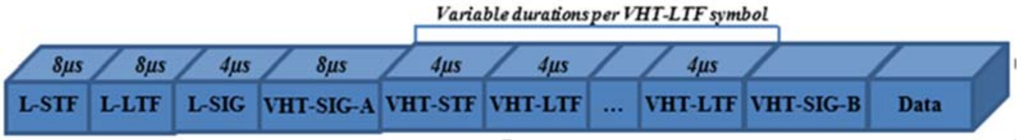

Figure 4:The frame format of VHT at PHY layer IEEE 802.11ac

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Table 1: Simulation Parameters

Parameters	Value	Parameters	Value	Parameters	Value
$Wmin$	16	T_{DIFS}	34 µs	T_{SYM}	8 µs
$Wmax$	1024	N_{ES}	1-2	T_{L-SIG}	4 µs
slot time σ	9 µs	R_{data}	29.3 – 780 Mbps	$T_{VHT-SIG-A}$	8 µs
$Lmachdr$	34 bits	T_{L-STF}	8 µs	$T_{VHT-SIG-B}$	8 µs
T_{SIFS}	16 µs	T_{L-LTF}	8 µs	T_{VHT_STF}	4 µs
$N_{SERVICE}$	16 bits	N_{DBPSL}	117-3120	T_{VHT_LTF}	4 µs
N_{TAIL}	6 bits	$APEP_{LENGTH}$	1500	T_{SYMS}	3.6 µs
ρ	1 µs	N_{VHTLTF}	Table 22-10 of [3]	T_{SYML}	4 µs

$$M = \begin{Bmatrix} 8 \times [N_{A_{MSDU}}(APEP_{LENGTH} + N_{FA_{OH}}) + N_{PHY\ Header}] + N_{SERVICE} + N_{TAIL} \times N_{ES}\,, & AMSDU \\ 8\, N_{AMPDU}(APEP_{LENGTH} + N_{FA\_OH} + N_{PHY\ Header})] + N_{SERVICE} + N_{TAIL} \times N_{ES}, & AMPDU \\ 8\, N_{AMPDU}(APEP_{LENGTH}.N_{AMSDU} + N_{FA\_OH} + N_{PHY\ Header}) + N_{SERVICE} + N_{TAIL} \times N_{ES}, & AMSDU/AMPDU \end{Bmatrix} \quad (18)$$

$$m_{STBC} = \begin{Bmatrix} 2 & for\ using\ STBC \\ 1 & otherwise \end{Bmatrix} \quad (19)$$

where, N_{DBPSL} refers to the number of bits per symbol, $APEP_{LENGTH}$ represents the payload size, N_{ES} indicates the number of binary convolutional code, where Space time block code (STBC) is a technique used in the IEEE802.11ac to enhance the reliability of the data transmission. T_{PH} is calculated by using Eq. (4-19) in Eq. (13). For basic access mechanism, the $T_s, and\ T_c$ are calculated as shown in the equations below:

$$T_S = T_{DIFS} + T_X + T_{SIFS} + T_{ACK} + 2\,\rho \quad (20)$$

$$T_C = T_{DIFS} + T_X + T_{ACK\_OUT} + \rho \quad (21)$$

$$T_{ACK\_OUT} = T_{ACK} + T_{SIFS} + \rho \quad (22)$$

The values of parameters $(T_{DIFS}, T_{SIFS}, T_{ACK}, and\ \rho)$, are listed in Table 1.

4. NUMERICAL RESULTS

The performance of IEE802.11ac with three different aggregation techniques (AMSDU, AMPSU, and AMSDU/AMPSU) are presented in this section. The throughput and MAC efficiency are considered a function of the number of aggregation frames in context of different modulation techniques as shown in Figures 5-7. For the first five frames aggregation, the curves in Figures 5 and 6 show that the AMSDU gives a better performance in term of the throughput and MAC efficiency compared with AMPDU for all types of modulation. The results show that efficiency is improved by 0.5% and increased the throughput by 1.5 Mbps for QPSK modulation. However, the highest throughput and efficiency values are not recorded for AMSDU. This is because the supreme size to be processed at the destination is restricted by 7935 bytes. In addition, the AMSDU is more affected by the channel error where any bits within a single MPDU corrupted leads to retransmit entire AMSDU.

(20)

(21)

From Figures 5 and 6, the AMPDU provides the maximum improvement for all types of modulation because of the maximum size of aggregated frame with AMPDU can arrive up to 65535 bytes. Moreover, the AMPDU is less effect by channel errors, where any error occurs in a single MPDU leads to retransmit it by the transmitter without effected on the others.

(22)

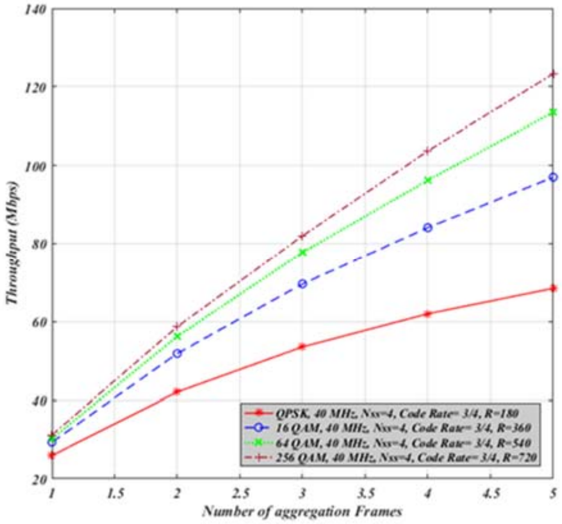

Figure 5.a: Throughput of four considered modulations with AMSDU

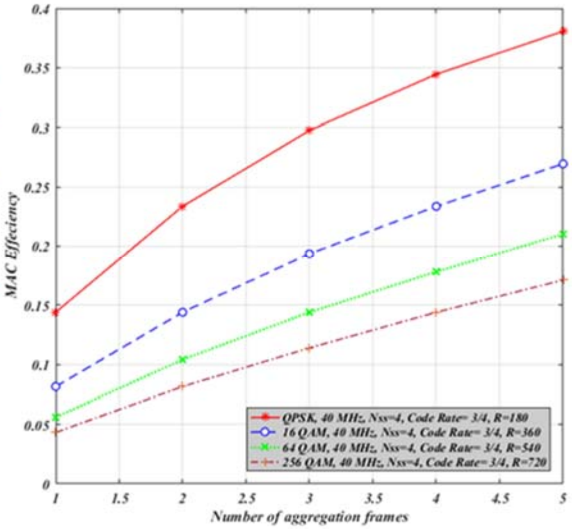

Figure 5.b: MAC efficiency of four considered modulations with AMSDU

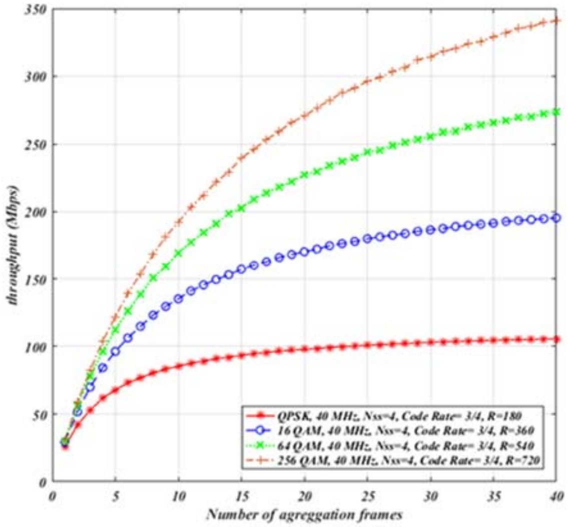

Figure 6.a: Throughput of four considered modulations with AMPDU

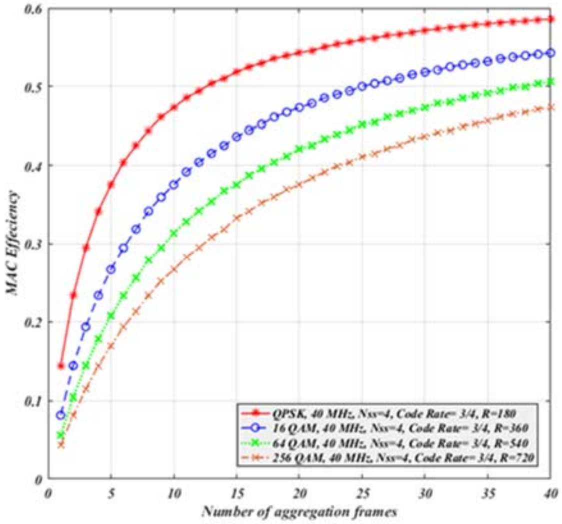

Figure 6.b: MAC efficiency of four considered modulations with AMPDU

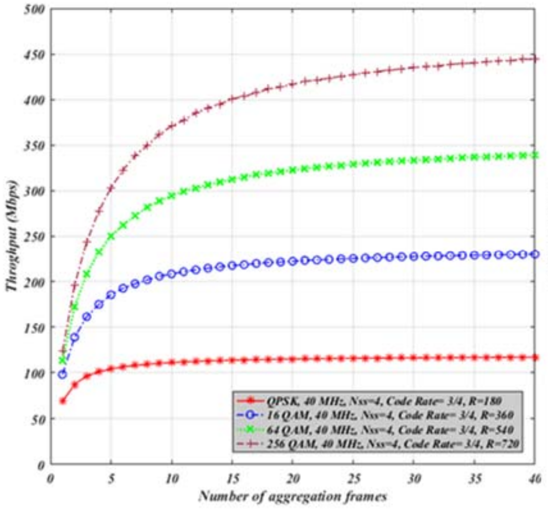

Figure 7.a: Throughput of four considered modulations with AMSDU/AMPDU

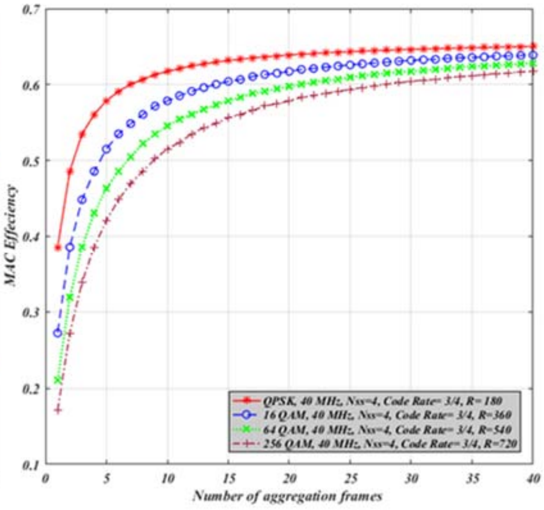

Figure 7.b. MAC efficiency of four considered modulations with AMSDU/AMPDU

On the other side, curves in Figures 6 and 7 show that using the proposed aggregation technique (AMSDU/AMPDU) gives highest throughput and best improvement in MAC efficiency with respect to the other aggregation techniques. It is obviously seen that using (AMPDU/AMSDU) with 256 QAM increase the throughput by 103.5 Mbps compared with AMPDU. For other modulation types such as 64QAM, 16QAM, and QPSK, the rises were 65.7 Mbps, 34.7 Mbps, and 11.5 Mbps, respectively. Concerning MAC efficiency, the amount of improvement is 24.81%, 23.17%, 20.31%, and 14.38% for 256QAM, 64QAM, 16QAM, and QPSK, respectively. The results are calculated when the number of aggregation frames is 10.

The curves in Figure 8 correspond to the throughput as a function of contented users with four-channel bandwidths such as (20, 40, 80, and 160) MHz, for different aggregation techniques (Conventional, AMPDU, and AMSDU/AMPDU). The calculated results are considered the following parameters QPSK with Spatial Streams = 4, short GI, code rate = 3/4. The size of AMSDU and AMPDU are fixed at 4095 bytes and 15870 bytes, respectively. The throughput declines while the number of contention stations increases for all aggregation mechanisms and the channel bandwidth. This declining because of the increasing probability of collision; which result fails the transmission process and requires an additional time for retransmitting packets. Nevertheless, for channel bandwidth 160 MHz, the throughput rises by 463.76 Mbps compared with 20 MHz. Also, for 80 MHz and 40 MHz, there is an improvement of almost 233.06 Mbps and 77.76 Mbps compared to 20 MHz. In addition, Figure 8 presents that the throughputs are sensitive to the aggregation techniques. For 160 MHz, the achieved throughput by the AMSDU/AMPDU rises to 278.2 Mbps and 502.17 Mbps higher than the AMPDU and conventional, respectively. The rest of throughput values are shown in Table 2.

Table 2: Performance comparison of Throughputs obtained from using AMSDU/AMPDU compared with another aggregation.

Channel Bandwidth	Maximum Throughput Mbps		
	Conventional	AMPDU	AMSDU/AMPDU
20 MHz	27.65	65.82	78.04
40 MHz	33.53	116.6	155.8
80 MHz	37.53	192.1	311.1
160 MHz	39.63	263.6	541.8

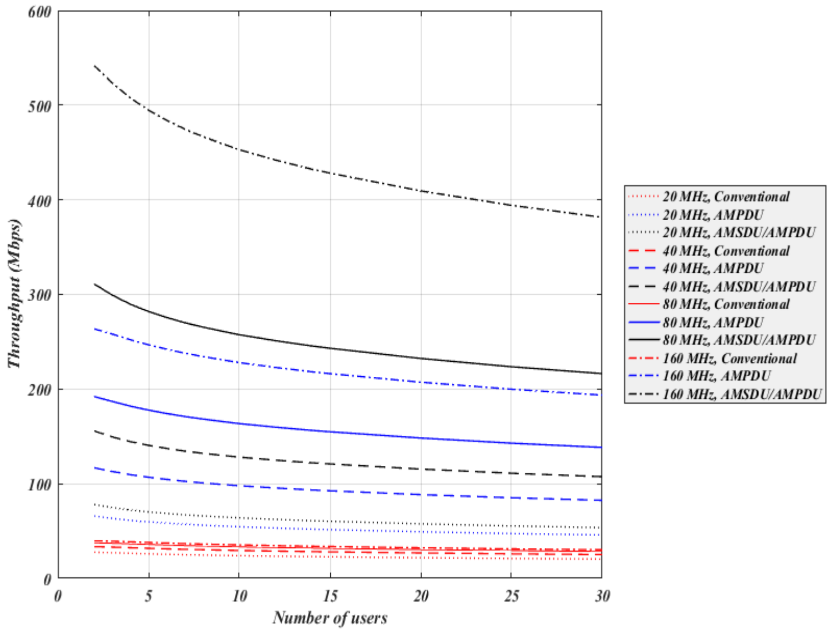

Figure 8: The effects of number of users on throughput for different bandwidth size

The throughput performance of different aggregation techniques as a function of various spatial streams (transmitter antennas) are described in Figure 9. In this case, the parameters consider channel bandwidth = 40 MHz, short GI, code rate = ¾ and number of stations = 25. The size of AMSDU fixed at 4095 bytes and AMPDU at 15870 bytes. The result shows that the throughput rises while the number of transmitter antennas increased. The duplicated number of transmit antennas leads approximately to duplicate the data rate transmission. This reduces amount of required time to transmit packets successfully. Also, the results show that AMSDU/AMPDU technique with 64QAM and 16 QAM achieves higher throughput compared with other aggregation techniques. For 64 QAM the maximum recorded throughput was 500 Mbps while for AMPDU and Conventional mode were 224.4 Mbps and 31.66 Mbps, respectively.

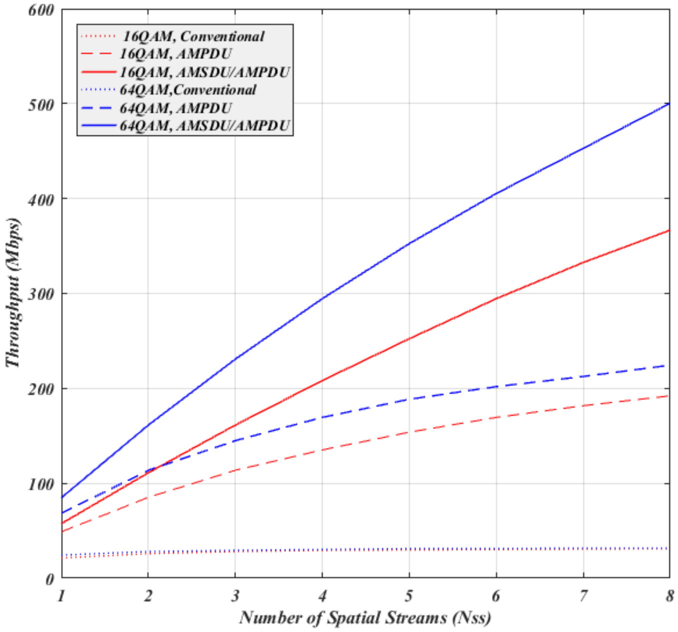

Figure 9: The effects of different aggregation techniques on throughput for different spatial stream

The throughput versus payload size with considering different coding rates such as 2/3, 3/4 and 5/6 are shown in Figure 10. The following parameters consider QPSK with SSs = 4. The results show that throughputs are affected according to the payload size where increasing the packet size leads to increase the throughput. Also, it demonstrated that lower throughput values are recorded for both the conventional and AMPDU techniques. The AMPDU stays below 75 Mbps and AMPDU below 41 Mbps, while AMSDU/AMPDU achieves maximum throughputs of 136 Mbps.

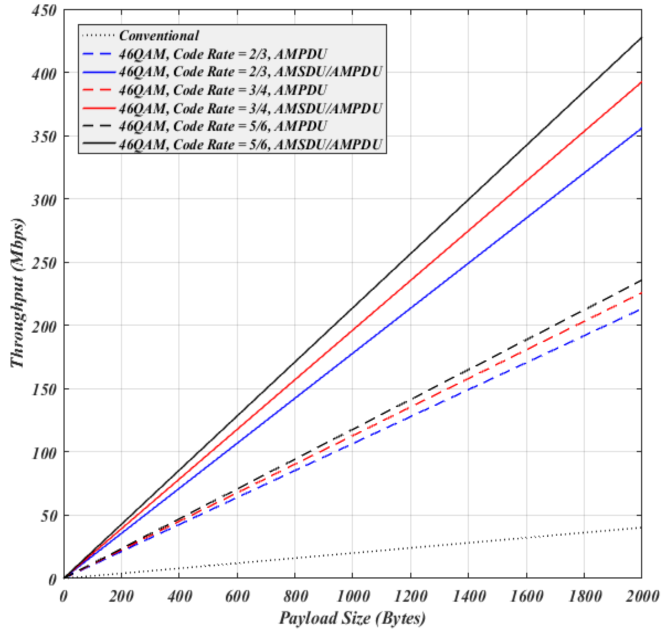

Figure 10: Effects different coding rates on throughput for different payload size

5. CONCLUTION

In this paper, the comparison between three different frame aggregation techniques namely, AMSDU, AMPDU, and hybrid AMSDU/AMPDU of IEEE802.11ac has been analyzed. The results demonstrate that using any types of aggregation mechanisms increase the throughput and improve the MAC efficiency compared with conventional techniques. The maximum throughput was risen up to 155.8 Mbps with the hybrid technique regarding with 40MHz and 4 spatial streams compared with 116.6 Mbps and 33.53 Mbps for AMPDU and AMSDU, respectively. In case of hybrid technique using 160 MHz bandwidth, the throughput is increased by 463.76 Mbps compared with 20 MHz bandwidth. For 80 MHz and 40 MHz of bandwidths, there is an improvement of approximately equal to 233.06 Mbps and 77.76 Mbps sequentially. Also, the number of antenna can directly increase the throughput. The modulation order of 64 QAM for hybrid was improved the throughput to 500 Mbps compared with 224.4 Mbps and 31.66 Mbps for AMPDU and AMSDU, respectively. In addition, increasing the coding rates will improve the throughput for all kinds of aggregation techniques. In the future, more work can be achieved on MAC layer in respect of frequency channel response and hidden node problem.

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