IEEE 802.11ac TXOP sharing technique: Performance evaluation

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Abstract

Sharing Transmission Opportunity period (TXOP) technique is recently defined by IEEE 802.11ac to allow simultaneous downlink transmissions. In this paper, we focus on the basis of this technique and the behavior of the access point (AP) to manage the multi-user access. We discuss the different steps required to allow simultaneous downlink transmissions. Based on simulation results, we prove that TXOP sharing technique has a significant positive impact on delay performance of different access categories (ACs).

Keywords: IEEE 802.11ac, Access category, TXOP sharing, downlink transmissions, delay.

I. INTRODUCTION

Actually, the IEEE 802.11ac standard is a Very High Throughput (VHT) wireless local area network (WLAN) that still being defined. It aims to achieve 7Gbps over 5 GHz bands [1][2], and to support point to-multipoint communications through new enhancements. At physical layer (PHY), it is based on Downlink Multi-user MIMO (DL MU-MIMO) technology [3][4] that allows multiple frames to be sent from the AP to multiple receivers simultaneously through multiple spatial streams.

To support multiple downlink traffic streams to multiple receiver STAs simultaneously, IEEE 802.11ac enhances the MAC layer by defining a new technique called TXOP sharing [5] work as an extension of the legacy EDCA TXOP that was proposed in the IEEE 802.11e[6] amendment. Based on this latter technique, when an access category (AC) gains an EDCA TXOP opportunity [7], only frames belonging to the same AC are transmitted. However, multiple frames belonging to different ACs are not allowed to be transmitted simultaneously. To overcome this inefficiency, TXOP sharing of an EDCA is proposed to allow the AP to perform simultaneous transmissions to multiple receiving STAs. This mode applies only to an AP that supports DL-MU-MIMO, and each EDCF of an AP uses its own EDCA parameters to compete for TXOP period.

There are numerous works studied and enhanced supporting multi-user transmissions. Authors in [8] enhanced channel sharing for multi-user access. They proposed to devise the channel into small sub-channels. Hence, each sub-channel is allocated for one user, so multiple users use the same channel. Authors in [9] interested on improving MU-MIMO technology. They proposed a new approach named "A Unified Down / Up-link MU-MIMO MAC" (Uni-MUMAC). Using the proposed concept, the AP can notify the uplink contending users about the number of available antennas and the channel state. Then, users can be synchronized for simultaneous uplink transmissions. Authors in [10] proposed a Markov chain-based analytical model for the TXOP sharing mechanism enabled at the 802.11ac AP to estimate the achievable throughput of a given AC. Authors proved that TXOP sharing mechanism could improve the utilization of the scarce wireless bandwidth while achieving channel access fairness among the different ACs.

In this paper, we will focus on EDCA TXOP sharing technique. First, we will discuss the steps invoked to allow multi-users communications. Then, we will investigate the behavior of the AP, as well as the active AC(s). Finally, we will evaluate the performance of TXOP sharing technique compared to EDCA TXOP technique.

The rest of this paper is organized as follows. We will give the meaning of the used abbreviations along the paper in Section 2. In Section 3, we will investigate TXOP sharing technique. Then, in Section 4, we will discuss the behavior of the AP for simultaneous downlink transmissions. Next, in Section 5, we will discuss the performance of this technique. Finally, Section 6 concludes the paper and discusses the future research challenges.

II. TERMINOLGY

First, we list the meanings of some keyworks which were frequently used among this paper.

- ✓ *Primary AC:* is the owner of the TXOP sharing period.
- ✓ *Secondary AC(s):* is composed by others AC(s) which have different destination as the Primary AC.
- ✓ *Compelementary AC:* AC(s) that have a similar destination as the Primary AC.
- ✓ *TXOP sharing period:* limited to TXOPLimit of the primary AC supports simultaneous transmissions.

III. TXOP SHARING TECHNIQUE

In IEEE 802.11e, when an AC gains an EDCA TXOP, only frames belonging to the same AC are transmitted. To overcome this inefficiency, IEEE 802.11ac proposes TXOP sharing of an EDCA allowing the AP to perform simultaneous transmissions to multiple receiving STAs.

Based on EDCA TXOP sharing technique, when an AC gains a TXOP, it will be the owner of this period, and it is considered as Primary AC while the remainders ACs are

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Secondary. The primary AC decides whether to share its TXOP with the secondary ACs for simultaneous transmissions. If it does, the won TXOP becomes a multi-user TXOP (MU-TXOP). The primary AC also decides which secondary AC(s) to share with it the won TXOP. The duration

of TXOP period is defined based on TXOP Limit of the Primary AC. Acknowledgements are sent back at the end of each downlink transmissions.

IV. Behavior of the Access Point for Downlink Multi-User Transmissions

Implemented within the AP, EDCA TXOP sharing technique is accomplished using two steps which are: i) Primary and Secondary AC(s) distinction, ii) Transmission process. Next sections detail the basis of each one.

A. Primary and Secondary AC(s) disctinction

IEEE 802.11ac defines two types of AC(s) which are: Primary and Secondary AC(s). Primary AC is the owner of the TXOP period while Secondary AC(s) are allowed AC(s) to transmit simultaneously during the same period. However, there are some AC(s) that are not able to share the primary TXOP period. In this work, we propose that these latter AC(s) will be named Complementary AC(s).

First, knowing the primary AC, the AP may distinguish between secondary and complementary AC(s). The former category is composed by AC(s) that don't have a similar destination (Dst) as the primary. So, they can proceed for simultaneous transmissions. The remainders are complementary AC(s). In fact, in downlink transmissions, the AP can't transmit all together numerous frames from different users to the same receiver.

We give in Table.1 an example of AC(s) types distinction. In this example, we consider four active AC[i]. AC[1] is Primary since it has highest priority. Station (1) is a primary destinations. Flows of AC[2] are addressed to station (3) which are different to primary destination; so AC[2] is a secondary. However, flows of AC[3] are addressed to station (1) which is a similar destinations as Primary AC flows. Hence, AC[3] is complementary AC.

Next, the primary AC will be the owner of the TXOP sharing period which is limited to its $TXOP_{limit}$. While secondary AC(s) are permitted to transmit in the same period, complementary AC(s) may transmit in a next period which is defined in this work as Complementary TXOP.

B. Transmission Process

Limited to $TXOP_{Limit}$ of primary AC, TXOP sharing period is divided into "n" equal periods, where "n" is the total number of ACs (Primary and secondary) that will share the TXOP period for simultaneous transmissions. In this paper, we designed each period as a TXOP Elementary period ($TXOP_{EL}$). During $TXOP_{EL}$, the AP transmits many frames from Primary and secondary AC(s) to different receivers. Frames that belong to the primary AC are transmitted in every $TXOP_{EL}$, while Secondary AC(s) transmissions are performed according to the priority level.
In fact, among Secondary AC(s), the AP transmit frames of highest priority in the first $TXOP_{EL}$; then frames of lower priority are sent in the next $TXOP_{EL}$. The AP can allow transmissions of many secondary AC(s) in the same $TXOP_{EL}$ if they have different destinations. Before switching to a next $TXOP_{EL,}$ the AP sends Block Acknowledgement Request (BAR) frames to destination STAs which respond immediately by sending BA frames.

When TXOPLimit is achieved, Complementary AC(s) are served while respecting priority levels. The AP transmits frames of each Complementary AC based on EDCA TXOP technique. In that case, if there are many Complementary AC(s), flows of lower priority AC may be transmitted once TXOP period of higher AC is achieved.

In Fig.1, we describe the transmission process based on EDCA TXOP sharing technique. In this example, we suppose that AC[1] is primary, AC[2] and AC[4] are secondary, and AC[3] is complementary. Then, TXOP period will be divided into three $TXOP_{EL}$. In every $TXOP_{EL}$, flows of AC[1] are sent to the appropriate destination. In the same period, flows of AC[2] are sent since they have the highest priority among secondary AC(s). The AP may transmit flows of AC[4] if they have different destination as AC[2]. Otherwise, it will be sent in the next $TXOP_{EL}$. When TXOP sharing period is achieved, flows of complementary AC(s) are transmitted in a TXOP complementary period regarding its priority level.
Based on IEEE 802.11e EDCA TXOP technique, flows of highest priority AC are transmitted in burst during the corresponding TXOP period which is limited to TXOPLimit. Then, flows of lower priority AC(s) are sent in burst during the matched TXOP period.

V. Performance Analysis

We have evaluated the performance of TXOP sharing technique comparaed to a simple EDCA TXOP transmissions considering the same priority queues. We carry out a performance analysis base on a custom-made simulator written in C++ programming language.

A. Assumptions

We considered four prioritized AC(s) contending to the medium. Downlink transmissions are performed to eight receiver stations. . Since the TXOP period of each AC is defined by IEEE 802.11e, the number of transmitted packets (N) can be expected as following:

$$N = \frac{(Payload\_Size\_of\_Consecutive\_Transmissions)}{(Payload\_Size\_of\_one\ packet)} \quad (1)$$

$$(Payload\_Size\_of\_Consecutive\_Transmissions) = Allocated\_duration\_for\_transmissions)* Data_{Rate} \quad (2)$$

$$Allocated\_duration\_for\_transmissions = \begin{cases} TXOP_{Limit} - m*(T_{BA+}\ T_{BAR+}SIFS);\ (If\ Primary) \\ TXOP_{EL} - m*(T_{BA+}\ T_{BAR+}SIFS);\ (If\ Secondary) \end{cases} \quad (3)$$

Table.1. AC(s) distinction: Example

ACs	Priority levels	Destination of Flows in AC[i]	AC Type
AC[1]	1	STA : 1	Primary
AC[2]	2	STA : 3	Secondary
AC[3]	3	STA : 1	Complementary
AC[4]	4	STA : 5	Secondary

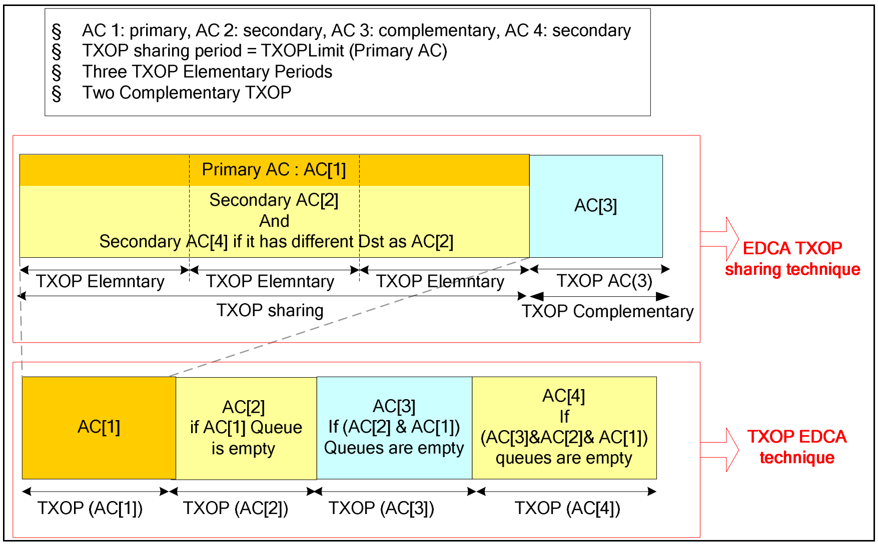

Figure 1. EDCA TXOP sharing technique Vs EDCA TXOP

Where $Data_{Rate}$ is the physical data rate, and the (Payload_Size_of_one packet) is given by Table 2. m*(T_{BA}+ T_{BAR} +SIFS) is the required delay to exchange acknowledgments between the AP and the "m" receiving stations. We assume that every source voice sends packets with mean rate equal to 64kbps as G.721 codec; video flows are sent as H.263 codec with mean rate equal to 640kbps; streaming flows are sent sends with 300kbps rate. We assumed that the inter-arrival time is equal to 3ms.

B. Simulation results

The two metrics of insterest are: delay (D) and throughput (Th). The measured delay is considered as the elapsed delay between the instant of packet generation until the serving instant. We consider the throughput as (4):

$$Th = \frac{L_{data}}{Delay_{transmission}} \quad (4)$$

Where L_{data} is the frame payload size, and $Delay_{transmission}$ corresponds to required transmission delay. This delay includes the inter-frame spacing delays such as $AIFS$, $SIFS$, the backoff delay $T_{backoff}$, the required delay to exchange BA, i,e T_{BAR} and T_{BA}, and the transmission delay of that frame. Figures 2, 3, 4, and 5 draw the average delay for every AC. The average throughput is plotted in Figure 6. Different scenarios are listed in Tables 3 and 4.

C. Results discussion

For different AC(s), the serving delay depends on consided scenrio. From Fig.2, we observe that TXOP sharing technique has no benefit for AC[1] flows compared to EDCA TXOP technique. In fact, AC[1] has always the highest priority under two techniques. Then, entering packets in the queue are immediately served.
From Fig.3, based on EDCA technique, flows of AC[2] are always served after AC[1]. Based on TXOP sharing technique, flows of AC[2] may be served simultaneously as AC[1] flows if AC[2] is secondary. Otherwise, it will be served in a complementary TXOP after achieving TXOPLimit(AC[1]), like scenario 7. When primary, AC[2] flows are immediately served like scenarios 5 and 6.
Fig.4 illustrtes that, based on EDCA TXOP scheme, flows of AC[3] are transmitted after achieving the TXOP periods of AC[1] and AC[2], similarly when it is complementary for TXOP sharing technique as scenarios 7 et 4. In scenario 2, AC[3] flows are transmissed in the second $TXOP_{EL}$ as it has the same destinations like the secondary AC[2].
The impact of using TXOP sharing technique on delay performance of AC[4] is given by Fig.5. Based on EDCA TXOP technique, AC[4] flows are served after TXOPLimit of AC[1], AC[2], and AC[3]. Based on TXOP sharing technique, when being secondary, AC[4] flows are immediately served with the primary AC if there is no higher priority secondary AC having the same destination.
The average throughput of different AC(s) is plotted in Fig.6. Based on TXOP sharing technique, being primary or secondary, or complementary can extremely modify throughput behavior. For primary, secondary and complementary, TXOP sharing technique engenders higher throughputs compared to EDCA TXOP technique. In fact, when the serving delay is reduced, higher rates are obtained since they are inversely related. Hence, highest rate are given for primary flows, while lower rate is matched to complementary flows. However, EDCA TXOP engenders lower rates as it causes higher delays.

Table.2. Simulation parameters

Queue	TXOPLimit (ms)	Packet size (Byte)
Unicast voice	1.504	120
Unicast video	3.008	660
Unicast streaming	-	1500

Table. 3. Simulation Scenarios
P: Primary, S: Secondary, C: Complementary

	AC[1]	AC[2]	AC[3]	AC[4]
Scenario 1	P	S	S	S
Scenario 2	P	S	S	C
Scenario 3	P	S	C	C
Scenario 4	P	C	C	S
Scenario 5	-	P	S	S
Scenario 6	-	P	C	S
Scenario 7	P	C	C	C

Table 4. Destination STA members of different scenarios

	AC[1]	AC[2]	AC[3]	AC[4]
Scenario 1	2	3	1	3
Scenario 2	3	4	4	3
Scenario 3	1	3	1	1
Scenario 4	1	1	1	7
Scenario 5	-	2	3	6
Scenario 6	-	5	5	2
Scenario 7	2	2	2	2

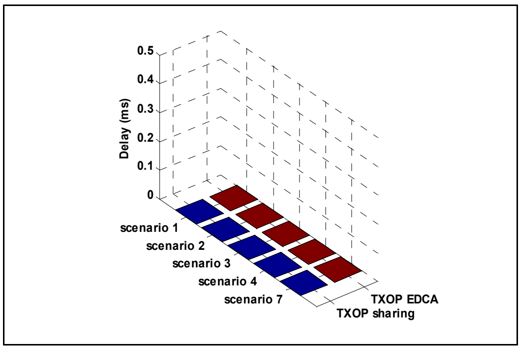

Figure.2. Delay for AC[1]

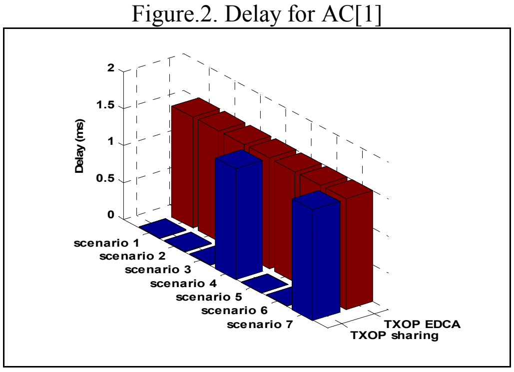

Figure.3. Delay for AC[2]

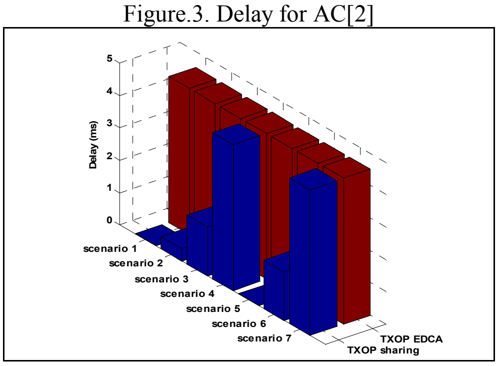

Figure.4. Delay for AC[3]

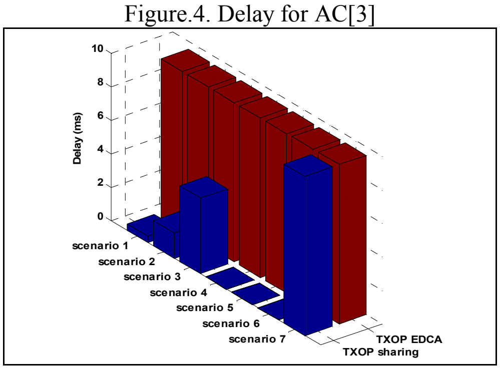

Figure.5. Delay for AC[4]

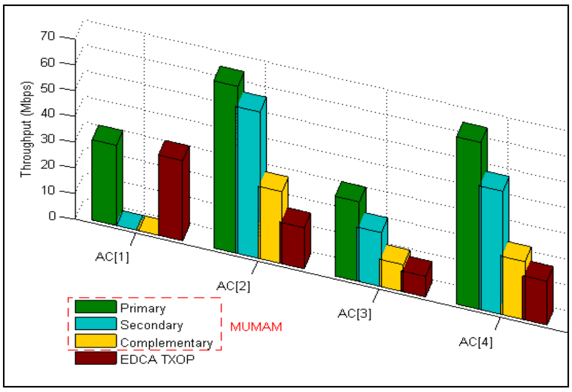

Figure.6. Average Throughput for different AC(s)

VI. CONCLUSION AND FUTURE WORKS

In this paper, we have investigated EDCA TXOP sharing technique which was proposed to support simultaneous downlink transmissions. Flows of lower priorities AC(s) are allowed to be served simultaneously in the TXOP period of the highest priority AC. We evaluated the performance of this technique compared to 802.11e EDCA TXOP transmission. Simulation results proved that sharing a TXOP period engenders lower delays and better throughput. Mainly, it has a significant positive impact on secondary and complementary AC(s).

As future work, we aim to improve the presented approach and design an advanced Multimedia-MAC with a dynamic scheduling based on traffic priority under saturated network condition.

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