**3GPP TSG RAN WG1 #114bis R1-2310513**

**Xiamen, China, October 9th – October 13th, 2023**

**Agenda item:** 8.17

**Source:** Moderator (Samsung)

**Title:** Summary of discussion on multiplexing HARQ-ACK in a PUSCH

**Document for:** Discussion and Decision

# Introduction

This contribution aims to collect and summarize company views on the issue of multiplexing HARQ-ACK in a PUSCH as raised in [1].

Please consider entering the contact information below for better coordination for this discussion.

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| **Company** | **Contact(s)** | **Email address(es)** |
| Samsung (Moderator) | Sa Zhang | sa.zhang@samsung.com |
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# Background

In RAN1#113 meeting, the following agreement was made.

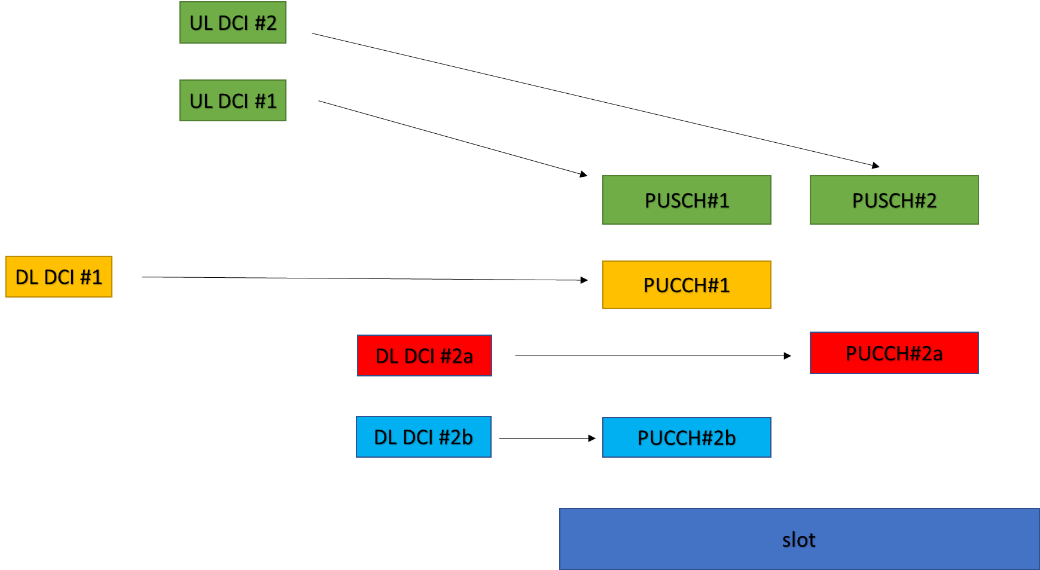
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| Agreement  If UCI multiplexing of different priorities is not enabled, the restriction on scheduling PDSCH after UL grant is removed for the case of PUSCH with repetitions except the first repetition   * UE generates Type-1 HARQ-ACK codebook according to the existing specification with the modification of setting the actual ‘ACK/NACK’ value corresponding to PDSCH(s) scheduled after the UL grant. * UE generates Type-2/3 HARQ-ACK codebook according to the existing specification.   + For Type-2 CB, UL DAI is used for generating HARQ CB. * This feature is subject to separate UE capabilities for type-1, type-2, and type-3 codebooks. * RRC parameter(s) to configure the function of scheduling PDSCH after a UL DCI format and multiplexing associated HARQ on a PUSCH repetition except the first repetition are introduced in Rel-18. * Note: the number of PUSCH repetitions can be scheduled/configured by gNB. * Note: same principle of current specification which UL DAI in UL grant is applied to each PUSCH repetition is reused. * The timeline specified in TS 38.213 Clause 9.2.5 are satisfied, i.e. between the last PDSCH and PUCCH, between the last PDCCH among UL grant /DL grant(s) and the earliest PUCCH or PUSCH * Additional UE capabilities are introduced to support the following functions (UE will be configured by gNB to use the following features via RRC)   + HARQ-ACK codebook size change on a PUCCH slot   + PUCCH resource change on a PUCCH slot |

It was pointed out in [1] that if the time domain of the PUCCH resource does not change before and after the UL grant, a UE does not need additional timeline to determine the PUSCH for HARQ-ACK multiplexing. It is proposed that the restriction on PUCCH resource change only impact time domain.

# Discussion

It was pointed out in [1] that when a DL assignment comes after an UL grant for a UE, the UE determines the HARQ-ACK codebook and a PUCCH resource based on the HARQ-ACK codebook size and the PRI indication in the last DCI format for DL assignment before the UL grant. After that, the UE multiplexes the HARQ-ACK in a PUSCH overlapping with the PUCCH, if any. If PUCCH time domain resource is different from the PUCCH that UE determines before the UL grant, UE may multiplex the HARQ-ACK in another PUSCH. As a result, it would take additional time for the UE to re-determine the PUSCH and the REs for both the HARQ-ACK and the data in the PUSCH.

An example is given in [1] to illustrate the issue as show in Figure 1. UE first determines to multiplex HARQ-ACK in PUCCH#1 before receiving the UL DCI#1 and UL DCI#2, and then UE determines to multiplex HARQ-ACK in PUSCH#1 after receiving the UL DCI#1 and UL DCI#2. If the UE receives DL DCI 2a, UE needs to re-determine the PUSCH for multiplexing based on the PUCCH resource indicated by DL DCI 2a. On the other hand, if UE receives DL DCI 2b indicating the same PUCCH time domain resource as PUCCH#1, the UE does not need to re-determine the PUSCH for HARQ-ACK multiplexing. The additional timeline is not required for this case. Therefore, the additional UE capability is not needed either.



**Figure 1**

**Q1: Do you agree that the PUCCH resource change in frequency domain does not impact the PUSCH determination for HARQ-ACK multiplexing, i.e., the UE determines the same PUSCH for HARQ-ACK multiplexing if the time domain resource of PUCCH does not change? If not, please clarify the reason.**

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| **Company** | **View** |
| Apple | No. UE has to determine the PUCCH resource for which the timeline needs to be met. At the time UE tries to re-determine the PUCCH resource, it does not know if the indicated PUCCH is in the same exactly overlaps in time with the previous one. Besides the toy example is quite problematic. As agreed in TEI, multiplexing a PUCCH associated with a DCI received after PUSCH DCI can happen, subject to UE capability, for repetitions EXCEPT the first repetition (for which UE still does not expect to receive a DCI after PUSCH DCI). |
| Mod | @Apple  Regarding your comment “UE has to determine the PUCCH resource for which the timeline needs to be met.” I think it is true if UE reports the capability of PUCCH resource change. However, if the UE does not report the capability, in this case, the PUCCH resource should be exactly the same as the one before UE receives the UL grant. UE does know time domain of the PUCCH resource won’t be changed and the indicated PUCCH is in the same exactly overlaps in time with the previous one, therefore the UE does not need to re-determine the PUCCH resource in the indicated PUCCH slot.  Regarding the concerns on the PUSCH, you can assume both are repetitions, for example as shown in the figure below. |
| CATT | We agree that the PUCCH resource change in frequency domain does not impact the PUSCH determination for HARQ-ACK multiplexing. |
| vivo | Agree the PUCCH resource change other than time domain does not impact the PUSCH determination for HARQ-ACK multiplexing. |
| Samsung | Agree |
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If a UE is capable of supporting the PUCCH resource change in the frequency but does not support PUCCH resource change in the time domain, the UE cannot report the capability of supporting PUCCH resource change based on the current agreement. In this case, gNB cannot indicate a different PUCCH resource after UL grant. This is very restrictive for the gNB scheduling. For example, if the size of HARQ-ACK codebook is no larger than 2 before the UL grant, gNB cannot schedule a DL grant resulting in the size of HARQ-ACK codebook larger than 2 because the PUCCH resource has to be changed for this case.

**Q2: Do you agree that the restriction on the PUCCH resource change in the frequency domain would put unnecessary restriction on gNB if UE is capable of supporting the PUCCH resource change in the frequency domain and does not support PUCCH resource change in the time domain? If not, please clarify the reason.**

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| **Company** | **View** |
| Apple | No, same comment as above |
| CATT | Agree |
| vivo | Agree |
| Samsung | Agree  We would like to further clarify that for PUCCH format 2/3, if the size of the HARQ-ACK codebook increases after receiving the later DL grant, the PRB of the PUCCH can be increased. If UE does not report the additional capability, it would be very restrictive for network scheduling. |
| Spreadtrum | Agree |
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To reduce the restriction on gNB scheduling, it is proposed in [1] that the previous agreement should only limit to PUCCH resource change in time domain.

**Q3: Do you agree with the following proposal? If not, please clarify the reason.**

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| **Proposal: Update the previous agreement made RAN1#113 as following,**  Agreement  If UCI multiplexing of different priorities is not enabled, the restriction on scheduling PDSCH after UL grant is removed for the case of PUSCH with repetitions except the first repetition   * UE generates Type-1 HARQ-ACK codebook according to the existing specification with the modification of setting the actual ‘ACK/NACK’ value corresponding to PDSCH(s) scheduled after the UL grant. * UE generates Type-2/3 HARQ-ACK codebook according to the existing specification.   + For Type-2 CB, UL DAI is used for generating HARQ CB. * This feature is subject to separate UE capabilities for type-1, type-2, and type-3 codebooks. * RRC parameter(s) to configure the function of scheduling PDSCH after a UL DCI format and multiplexing associated HARQ on a PUSCH repetition except the first repetition are introduced in Rel-18. * Note: the number of PUSCH repetitions can be scheduled/configured by gNB. * Note: same principle of current specification which UL DAI in UL grant is applied to each PUSCH repetition is reused. * The timeline specified in TS 38.213 Clause 9.2.5 are satisfied, i.e. between the last PDSCH and PUCCH, between the last PDCCH among UL grant /DL grant(s) and the earliest PUCCH or PUSCH * Additional UE capabilities are introduced to support the following functions (UE will be configured by gNB to use the following features via RRC)   + HARQ-ACK codebook size change on a PUCCH slot   + PUCCH time domain resource change on a PUCCH slot |

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| **Company** | **View** |
| Apple | No, same comment as reply to Q1 |
| CATT | Agree |
| vivo | Agree |
| Samsung | Agree |
| Spreadtrum | Agree |
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# Conclusion

During the discussion, four companies are supportive for the proposal, Apple shows some concerns on the UE re-determining the PUCCH resource. However, the re-determination of PUCCH resource and result PUSCH may not be needed if the UE does not report the UE capability because in this case UE already knows the PUCCH resource won’t be changed with or without the re-determination. The result PUSCH cannot be changed either. On the other hand, it the UE does not report the additional capability, it is very restrictive for gNB scheduling. Both the PUCCH format and number of PRB cannot be changed. To relax the gNB scheduling restriction and make the feature useful, the following proposal is suggested.

**Proposal: Update the previous agreement made RAN1#113 as following,**

Agreement

If UCI multiplexing of different priorities is not enabled, the restriction on scheduling PDSCH after UL grant is removed for the case of PUSCH with repetitions except the first repetition

* UE generates Type-1 HARQ-ACK codebook according to the existing specification with the modification of setting the actual ‘ACK/NACK’ value corresponding to PDSCH(s) scheduled after the UL grant.
* UE generates Type-2/3 HARQ-ACK codebook according to the existing specification.
  + For Type-2 CB, UL DAI is used for generating HARQ CB.
* This feature is subject to separate UE capabilities for type-1, type-2, and type-3 codebooks.
* RRC parameter(s) to configure the function of scheduling PDSCH after a UL DCI format and multiplexing associated HARQ on a PUSCH repetition except the first repetition are introduced in Rel-18.
* Note: the number of PUSCH repetitions can be scheduled/configured by gNB.
* Note: same principle of current specification which UL DAI in UL grant is applied to each PUSCH repetition is reused.
* The timeline specified in TS 38.213 Clause 9.2.5 are satisfied, i.e. between the last PDSCH and PUCCH, between the last PDCCH among UL grant /DL grant(s) and the earliest PUCCH or PUSCH
* Additional UE capabilities are introduced to support the following functions (UE will be configured by gNB to use the following features via RRC)
  + HARQ-ACK codebook size change on a PUCCH slot
  + PUCCH time domain resource change on a PUCCH slot

# Reference

[1] [R1-2309416](file:///F:\3GPP\RAN1\TSGR1_114b\Docs\R1-2309416.zip) Remaining issue for HARQ-ACK multiplexing on PUSCH Samsung