**3GPP TSG RAN WG1 Meeting #110 R1-220xxxx**

**e-Meeting, May 9th – 20th, 2022**

**Agenda item: 7.2.2**

**Source: Moderator(ZTE)**

**Title: Summary of HARQ-ACK multiplexing on PUSCH**

**Document for:** **Discussion and Decision**

# Introduction

This document summarizes the discussion on the issue of HARQ-ACK multiplexing on PUSCH proposed by [1].

# Discussion

In [1], it raises an issue of HARQ-ACK multiplexing on PUSCH. In unlicensed band, an UL DCI can schedule multiple PUSCHs in one or more slots. The PUCCH with HARQ-ACK may overlap with any one of the multiple PUSCHs. When the UE misses the DL DCI while the UL DCI indicates that the HARQ-ACK is multiplexed in the PUSCH, the UE does not know in which PUSCH the HARQ-ACK should be multiplexed since the UE does not know which PUSCH overlaps with the PUCCH resource.

Note that, similar issue due to missing DL DCI has been resolved under AI 7.1 in RAN1#109-e for licensed band. More details could be found in [1].

To resolve this issue, the following proposal and CR are provided.

***Proposal 1:*** *The HARQ-ACK information should be multiplexed in the first PUSCH of the multiple scheduled PUSCHs when the T-DAI in the UL grant is not equal to 4 for Type-2 codebook or is equal to 1 for Type-1 codebook.*

**CR for TS38.213**

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| If a UE multiplexes aperiodic CSI in a PUSCH and the UE would multiplex UCI that includes HARQ-ACK information in a PUCCH that overlaps with the PUSCH and the timing conditions for overlapping PUCCHs and PUSCHs in clause 9.2.5 are fulfilled, the UE multiplexes only the HARQ-ACK information in the PUSCH and does not transmit the PUCCH.  When a UE transmits multiple PUSCHs on respective serving cells in a slot with reference to slots for PUCCH transmissions and the multiple PUSCHs overlap with a PUCCH carrying UCI in the slot, the UE selects all the PUSCHs overlapping with the PUCCH as the candidate PUSCHs for UCI multiplexing within the slot.  If a UE would transmit a single PUSCH scheduled by a DCI format that includes a DAI field on a serving cell in a slot with reference to slots for PUCCH transmissions without any other PUSCH that would be transmitted on any serving cell in the slot and the UE does not determine any PUCCH carrying HARQ-ACK information in the slot, or if the UE indicates the corresponding capability *Multiplexing-HARQ-ACK-without-PUCCH-on-PUSCH* and the UE transmits multiple PUSCHs on respective serving cells in a slot with reference to slots for PUCCH transmissions and the UE does not determine any PUCCH carrying HARQ-ACK information in the slot and at least one of the multiple PUSCHs is scheduled by a DCI format that includes a DAI field, the UE selects the single PUSCH or all the multiple PUSCHs in the slot as the candidate PUSCHs for HARQ-ACK multiplexing within the slot except for any PUSCH among the multiple PUSCHs that is scheduled by a DCI format that includes a DAI field that is equal to 4 in case the UE is configured with *pdsch-HARQ-ACK-Codebook = dynamic* or with *pdsch-HARQ-ACK-Codebook-r16*, or is equal to 0 in case the UE is configured with *pdsch-HARQ-ACK-Codebook = semi-static*. If the UE does not determine any PUCCH carrying HARQ-ACK information in the slot, and multiple PUSCHs are signalled by SLIVs in the row of the *pusch-TimeDomainAllocationListForMultiPUSCH* in DCI format 0\_1 which includes a DAI field that is not equal to 4 in case the UE is configured with *pdsch-HARQ-ACK-Codebook* = *dynamic* or with *pdsch-HARQ-ACK-Codebook-r16* or is equal to 1 in case the UE is configured with *pdsch-HARQ-ACK-Codebook* = *semi-static*, the UE selects the first PUSCH of the multiple PUSCHs as candidate PUSCH.  The UE determines the PUSCH for UCI multiplexing by applying the following procedure on the candidate PUSCHs as described in this clause:  - If the candidate PUSCHs include first PUSCHs that are scheduled by DCI formats and second PUSCHs configured by respective *ConfiguredGrantConfig* or *semiPersistentOnPUSCH*, and the UE would multiplex UCI in one of the candidate PUSCHs, and the candidate PUSCHs fulfil the conditions in clause 9.2.5 for UCI multiplexing, the UE multiplexes the UCI in a PUSCH from the first PUSCHs.  - If the UE would multiplex UCI in one of the candidate PUSCHs and the UE does not multiplex aperiodic CSI in any of the candidate PUSCHs, the UE multiplexes the UCI in a PUSCH of the serving cell with the smallest *ServCellIndex* subject to the conditions in clause 9.2.5 for UCI multiplexing being fulfilled. If the UE transmits more than one PUSCHs in the slot on the serving cell with the smallest *ServCellIndex* that fulfil the conditions in clause 9.2.5 for UCI multiplexing, the UE multiplexes the UCI in the earliest PUSCH that the UE transmits in the slot.  **<Unchanged parts are omitted>** |

## First round

Companies are invited to share the views on the proposal and CR.

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| **Company name** | **Comments** |
| Intel | We are supportive to the proposal. The behaviour for HARQ-ACK multiplexing on multi-PUSCH transmission scheduled by a UL grant with UL DAI not equal to 4 for Type2 codebook or equal to 1 for Type1 codebook should be clarified. Exact wording to a TP can be discussed after a decision on the proposal. |
| Qualcomm | Fine the proposal and TP |
| Ericsson | Not support.  The procedure is based on UL slot with references to PUCCHs.  Also, the CR doesn’t reflect the proposal.  It seems the proponent intends to cover the case that there is no PUCCH detected in any of the UL PUCCH slots that include PUSCHs scheduled by a single DCI.  If that is the intension, the agreed behaviour for PUSCH repetition. But also in that case, one has to make sure that all the PUSCHs are the candidate PUSCHs for HARq-ACK multiplexing in respective UL slot. |
| ZTE | We support the proposal. If the current procedure is based on per PUCCH slot, it would mean the UE should multiplex UCI on all the multiple PUSCHs. |
| LG | Not support.  How to handle the case where there is no PUCCH collided with PUSCH in a slot had been agreed and already specified in current spec, i.e., the PUSCH is considered as candidate PUSCH for UCI multiplexing by the UE. Then the handling behavior would be applied per each of slots scheduled by multi-PUSCH scheduling DCI according to current spec, therefore no spec change is needed. |

## Second round

Based on online discussion, there could be two alternative solutions for this issue as below.

**Proposal 1:** For Rel-16 multi-PUSCHs scheduled by DCI format 0\_1, if a UE does not determine a PUCCH with HARQ-ACK that overlaps with the multi-PUSCHs, and if the UL-TDAI is not equal to 4 (for Type 2 codebook) or equal to 1 (for Type 1 codebook),

Option 1: the UE multiplexes HARQ-ACK following the UL-TDAI into each of the multi-PUSCHs.

* Ericsson, LG
* It is argued that there is no spec impacts for this option.

Option 2: the UE multiplexes HARQ-ACK following the UL-TDAI into the first PUSCH of the multi-PUSCHs.

* Intel, ~~QC~~, ZTE

From moderator perspective, current specification could be interpreted as Option 1. In addition, Option 2 potentially cause some issues. For instance, if gNB schedules a PUCCH overlapping with the second PUSCH while UE misses the DL DCI, gNB would assume UE will multiplex UCI in the second slot but UE actually multiplexes the UCI into the first slot.

**Based on above, moderator would like to check whether companies could go with Option 1 without additional spec impacts.**

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| **Company name** | **Comments** |
| Intel | Our understanding on the basic assumption of Option 1 is to determine the UCI multiplexing behaviour per slot. If so, does it mean UE should ALWAYS reserve UCI REs in ALL the PUSCHs of multi-PUSCH?   * If UE doesn’t have any PUCCH but UL DAI not equal to 4, UCI REs are reserved in each PUSCH   Moderator: The UCI REs are not reserved. The UE would multiplex HARQ-ACK on the REs in each PUSCH according to the indication of UL DAI.   * If UE has a PUCCH in a slot of the multi-PUSCH, but there is no PUCCH in remaining PUSCHs of the multi-PUSCH, then, should UE piggyback UCI on the PUSCH in the PUCCH slot with PUCCH and reserve UCI REs in other PUSCHs of the multi-PUSCH   Moderator: Similar as above, the UE would multiplex HARQ-ACK in each PUSCH. |
| Moderator | From moderator perspective, Option 1 (claimed as existing specified solution) is not optimal (causing unnessary multiplexing but more robust in NR-U scenario). On the other hand, it seems no other perfect solution on the table now either. In such situation, Option 1 seems still the default way to go.  **Proposed conclusion:**  For Rel-16 multi-PUSCHs scheduled by DCI format 0\_1, if a UE does not determine a PUCCH with HARQ-ACK that overlaps with the multi-PUSCHs, and if the UL-TDAI is not equal to 4 (for Type 2 codebook) or equal to 1 (for Type 1 codebook), the UE multiplexes HARQ-ACK following the UL-TDAI into each of the multi-PUSCHs.   * No specification impact is expected. |
| QC | After we review the spec, we think this issue is similar to HARQ-ACK overlapping with PUSCH with repetitions. In that case, HARQ-ACK is not multiplexed on PUSCH if PDCCH is missed. We think that the same solution might be applied to here as well. We suggest to consider add this solution as option 3 in proposal 1. Maybe we can further study these three options and make a decision in next meeting.  “If a UE transmits a PUSCH over multiple slots and the UE would transmit a PUCCH with HARQ-ACK and/or CSI  information over a single slot that overlaps with the PUSCH transmission in one or more slots of the multiple slots, and  the PUSCH transmission in the one or more slots fulfills the conditions in clause 9.2.5 for multiplexing the HARQACK  and/or CSI information, the UE multiplexes the HARQ-ACK and/or CSI information in the PUSCH transmission  in the one or more slots. **The UE does not multiplex HARQ-ACK and/or CSI information in the PUSCH transmission in**  **a slot from the multiple slots if the UE would not transmit a single-slot PUCCH with HARQ-ACK and/or CSI**  **information in the slot in case the PUSCH transmission was absent.”** |

# Reference

1. [R1-2205947](file:///C:\Users\younsun\Documents\3GPP%20documents\RAN1%20tdocs\TSGR1_110\Docs\R1-2205947.zip) Discussion on HARQ-ACK multiplexing on PUSCH ZTE