**3GPP TSG RAN WG1 Meeting #109-e R1-220xxxx**

**e-Meeting, May 9 – 20, 2022**

**Source: Moderator (Apple)**

**Title: Summary for [109-e-NR-CRs-01] HARQ-ACK multiplexing on PUSCH without PUCCH**

**Agenda item: 7.1**

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

# Introduction

This document provides the summary for the following email discussion in RAN1#109-e:

109-e-NR-CRs-01] Issue#1 Discussion on HARQ-ACK multiplexing on PUSCH with contributions [1], [2], [3], [4], ,[5] and [6](see the Appendix in Section 5 for a list of the proposals).

In RAN1 #106-e, there was a discussion on the topic with a summary of the status of the discussion for Rel-15 UE behavior as follows [10][11]:

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| Conclusion* *For Rel-15, in the case of multiple overlapping PUSCHs with no overlapping PUCCH and if any  UL-TDAI n.e. 4 (for Type 2 codebook) or UL-TDAI e.q. 1 (for Type 1 codebook) the UE behavior is left to UE implementation.*

Agreement* *For Rel-15 with more than one non-overlapping PUSCH and no overlapping PUCCH within a span on one slot (both single carrier and UL CA) and if*the UL-TDAI for the PUSCH*UL-TDAI not equal to 4 (for Type 2 codebook) or UL-TDAI equal to 1 (for Type 1 codebook), the UE behavior is up to the UE implementation*
* *For Rel-15 with one PUSCH and no overlapping PUCCH within a span of one slot and if*the UL-TDAI for the PUSCH*UL-TDAI not equal to 4 (for Type 2 codebook) or UL-TDAI equal to 1 (for Type 1 codebook), there is no consensus for any conclusion on one aligned UE behavior.*
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In RAN1 #107-e, there was a discussion on the topic with a summary of the status of the discussion for Rel-16 UE behavior as follows [12][13]:

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| **Agreement**For Rel-16 with multiple overlapping PUSCHs with no overlapping PUCCH with HARQ-ACK within a span of one PUCCH slot, if the UL-TDAI n.e. 4 (for Type 2 codebook) or equal to 1 (for Type 1 codebook) there is no consensus in RAN1 on Rel-16 UE behaviour  **Agreement**For Rel-16 with one PUSCH and no overlapping PUCCH with HARQ-ACK within a span of one PUCCH slot (both single carrier and UL CA), 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 the PUSCH. |

In summary, we have the following status:

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| **Scenario** | **Agreements/Conclusions/Status** |
|  Case 0: multiple overlapping PUSCHs with no overlapping PUCCH | For Rel-15, in the case of multiple overlapping PUSCHs with no overlapping PUCCH and if any  UL-TDAI n.e. 4 (for Type 2 codebook) or UL-TDAI e.q. 1 (for Type 1 codebook) the **UE behavior is left to UE implementation** |
| Case 1, Case 2, Case 3 : more than one non-overlapping PUSCH and no overlapping PUCCH within a span on one slot (both single carrier and UL CA) | For Rel-15 with more than one non-overlapping PUSCH and no overlapping PUCCH within a span on one slot (both single carrier and UL CA) and if the UL-TDAI for the PUSCH UL-TDAI not equal to 4 (for Type 2 codebook) or UL-TDAI equal to 1 (for Type 1 codebook), **the UE behavior is up to the UE implementation** |
| Case 4 : one PUSCH and no overlapping PUCCH within a span of one slot | For Rel-15 with one PUSCH and no overlapping PUCCH within a span of one slot and if the UL-TDAI for the PUSCH UL-TDAI not equal to 4 (for Type 2 codebook) or UL-TDAI equal to 1 (for Type 1 codebook), there **is no consensus for any conclusion on one aligned UE behavior**. |

In RAN1 #107-e [6], the following conclusions and agreements were made for Rel-16 UEs:

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| **Scenario** | **Agreements/Conclusions/Status** |
| Case 0: multiple overlapping PUSCHs with no overlapping PUCCH | For Rel-16 with multiple overlapping PUSCHs with no overlapping PUCCH with HARQ-ACK within a span of one PUCCH slot, if the  UL-TDAI n.e. 4 (for Type 2 codebook) or equal to 1 (for Type 1 codebook) **there is no consensus in RAN1 on Rel-16 UE behavior** |
| Case 1, Case 2, Case 3 : more than one non-overlapping PUSCH and no overlapping PUCCH within a span on one slot (both single carrier and UL CA) | Continue discussion on UE behavior with respect to multiplexing HARQ-ACK in PUSCH for the following case in Rel-16:More than one non-overlapping PUSCH and no overlapping PUCCH with HARQ-ACK within a span on one PUCCH slot (both single carrier and UL CA), if for at least one of the PUSCHs the UL-TDAI is not equal to 4 (for Type 2 codebook) or  equal to 1 (for Type 1 codebook) |
| Case 4 : one PUSCH and no overlapping PUCCH within a span of one slot | For Rel-16 with one PUSCH and no overlapping PUCCH with HARQ-ACK within a span of one PUCCH slot (both single carrier and UL CA), 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 the PUSCH**. |

In RAN1 108-e [14], there **was consensus on the need for a unified solution for Rel-16 based on the concept of a “virtual PUCCH” spanning the PUCCH slot**. The outstanding issues focused on (a) how the UE selects the candidate PUSCHs and (b) how the gNB sets the TDAI values for the candidate PUSCHs.

# 1st Round

### Issue 1: Rel-16 Unified Solution

There is consensus to use the following a unified framework solution for Rel-16 and the future. From past discussions, items 2 and 3 below (in green) are stable

1. Selection of the candidate PUSCH for multiplexing
	1. **Candidate PUSCHs**
		1. **Alt-1:** All the PUSCHs within the PUCCH slot are candidates
		2. **Alt-2:** PUSCHs without UL-TDAI=4 in case Type 2 CB, and without UL-TDAI n.e. 1 in case of Type 1 CB within the PUCCH slot are candidates
	2. N/W sets all TDAI values that overlap with PUCCH to the [same/different] value with TDAI n.e. 4
2. Prioritization rules to select PUSCH for multiplexing. Prioritization rules are identical to 38.213
3. Limitations for multiplexing
	1. UE expects to multiplex HARQ-ACK on only 1 PUSCH selected based on step 2 in the PUCCH slot.
	2. All the PUSCHs in the determined candidate set after step 1 have to satisfy Rel-15 UCI multiplexing timeline, defined with respect the starting symbol of the earliest PUSCH transmission in the candidate set**.**

This framework agrees to the following:

1. Use a “virtual PUCCH”
2. Consensus on using the Rel-15 prioritization framework
3. Consensus on having suitable limitations for multiplexing

To facilitate the discussion, we will discuss UE behavior and network behavior separately.

### Issue 1.1 UE behavior: Candidate PUSCH selection and Rel-16 capability

**Selection of the candidate PUSCH for multiplexing:**

* **Alt 1:** All the PUSCHs within the PUCCH slot are candidates
* **Alt 2:** PUSCHs without UL-TDAI=4 in case Type 2 CB, and without UL-TDAI n.e. 1 in case of Type 1 CB within the PUCCH slot are candidates

Company Positions:

* Alt 1: Ericsson, Nokia/NSN, Apple, LG
* Alt 1 Advantage: (Ericsson/Nokia) specify behavior for the case that PUCCH is absent should not diverge from the specified behavior when a PUCCH would be present
* Alt 1 issue: (CATT) additional scheduling restriction requirement is needed for Option 1, e.g. whether UCI multiplexing timeline needs to be satisfied even for the DCI(s) associated with PUSCH(s) in a PUCCH slot which do not overlap with the PUCCH.
* Alt 2: ZTE, Huawei/Hi-Silicon, CATT, Intel, Apple
* Alt 2 Advantage: reduces potential for mis-alignment by gNB and UE
* Alt 2 issue:
	+ (Ericsson) Changes operation from “PUSCH candidate selection then TDAI operation” to “TDAI operation then PUSCH candidate selection”
	+ (LGE) Does this account for account for CG-based and PUSCHs scheduled by fallback DCI
		- 38.213, Section 9: *If a UE transmits multiple PUSCHs in a slot on respective serving cells that include first PUSCHs that are scheduled by DCI format(s) 0\_0 or DCI format(s) 0\_1 and second PUSCHs configured by respective ConfiguredGrantConfig or semiPersistentOnPUSCH, and the UE would multiplex UCI in one of the multiple PUSCHs, and the multiple PUSCHs fulfil the conditions in Subclause 9.2.5 for UCI multiplexing, the UE multiplexes the UCI in a PUSCH from the first PUSCHs*
		- *Answer: Yes. Current language does not exclude CG and fallback DCI.*

###  Question 1: Alt-1 vs Alt-2

* **Alt 1:** All the PUSCHs within the PUCCH slot are candidates
* **Alt 2:** PUSCHs without UL-TDAI=4 in case Type 2 CB, and without UL-TDAI n.e. 1 in case of Type 1 CB within the PUCCH slot are candidates

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| **Company** | **Comments** |
| NTT DOCOMO | Our preference is Alt 2 since NW can avoid different understanding of which PUSCH HARQ-ACK is multiplexed on, between UE and gNB. In Alt 1, this avoidance is impossible.However, we can be flexible if majority support Alt 1. |
| LG | We prefer Alt 1 (and add “LG” as proponent of Alt 1 in above) to keep consistent UE behavior with the case when the HARQ-ACK PUCCH is present.  |
| MTK | We tend to agree with DOCOMO and slightly prefer Alt 2. However, in theory Alt 1 can still work that UE just ignores TDAI value and choose one PUSCH to do the multiplexing, and forgot the confusing T-DAI combinations. Hence, we can also be flexible to take Alt. 1 if NW vendors have strong concerns on Alt 2. |

**Rel-16 implementations:**

In RAN1 #108-e, concerns were raised by companies on the adoption of the unified solution for Rel-16 UE implementations. Option 3 of [14] and the following observation from Ericsson/Nokia [5] were proposed to resolve this issue:

1. *Introduction of capability for the solution can ease the UE implementations concern. While the behavior is specified and implemented by UEs, the presence of a capability improves the system performance due to less UEs with unknown behaviour in the NW.*

###  Recommendation 1: CR capability

Accept capability indicating that a Rel-16 UE can implement this CR

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| **Company** | **Comments** |
| NTT DOCOMO | Our preference is not to introduce UE capability for this topic, but we can accept it. |
| LG | We are open to consider the UE capability for this issue. |
| MTK | We support to introduce a new R16 UE capability for this CR. |

###  Issue 1.2 : Network Behavior: NW set TDAI value.

**Selection of the candidate PUSCH for multiplexing:**

* **Alt 2-1:** The N/W can set all TDAI values that overlap with PUCCH to different values with TDAI n.e. 4 i.e. no specification impact.
* **Alt 2-2:** The N/W should set all TDAI values that overlap with PUCCH to the same value with TDAI n.e. 4 i.e. will need to be specified.

Company Positions from contributions:

* Alt 2-1: Ericsson, Nokia/NSN, Apple, CATT, LGE
* Alt 2-2: ZTE, Huawei/Hi-Silicon, Intel, Apple

In the last meeting, it was shown by some network vendors that they currently utilize the flexibility afforded by the fact that this network behavior is not currently mandated by the specification. As such, it may be better to leave it to network implementation as is currently the case. Note that this does not impact the UE implementation as it only excludes TDAI = 4

**Recommendation:** Leave to gNB implementation. No specification impact.

###  Recommendation 2: Network behavior

Leave to gNB implementation i.e. no specification impact.

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| **Company** | **Comments** |
| NTT DOCOMO | We support Alt 2-2. If we go with Alt 2-1, ‘no specification impact’ should be ensured.  |
| LG | We support Alt 2-1 since there is no critical reason to have impact to the current spec. |
| MTK | We slightly prefer Alt 2-2. If different T-DAI values exist in the same PUCCH slot, UE would be confused about how many DL DCIs are missed. For example, there are 3 overlapping PUSCHs in the same PUCCH slot, and their T-DAI values are 1, 2, 3 respectively, it is confusing how can we have different number of missing DCIs in the same slot.Having said that, if NW vendors have strong concerns on Alt 2-2, then we can be flexible to take Alt 2-1, since it seems to still work if UE just follows the prioritization rule to choose one PUSCH. |

###  Question 2: Repetition for Rel-16 UEs

Please indicate preference and why:

For a Rel-16 UE, when a PUSCH scheduled by DCI is repeated and the corresponding UL grant indicates UL-TDAI but a PUCCH with HARQ-ACK is absent throughout the PUSCH repetition,

* Alt 3-1: 1st PUSCH repetition within PUCCH slot is selected
* Alt 3-2: UE does not multiplex HARQ-ACK in any of the PUSCH repetition

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| **Company** | **Comments** |
| NTT DOCOMO | We slightly prefer Alt 3-1.BTW, this question should be after section 2.1.14, right? Repetition issue seems discussed under section 2.1.13. |
| LG | We prefer Alt 3-2 to respect the previous relevant agreement. |
| MTK | We prefer Alt 3-2 to respect the previous relevant agreement; but we understand some NW vendors may prefer Alt 3-1 and we are willing to further discuss if there are clear benefits for NW to choose Alt 3-1. |

### Issue 2: Text Proposals for Agreements

We will work on the TPs in parallel with the general agreement.

###  Issue 2-1: TP for agreement in RAN1 #107-e

This proposal is based on an update from the version in R1-2204554 [5]. In RAN1#107-e, the following agreement was made:

**Agreement**

For Rel-16 with one PUSCH and no overlapping PUCCH with HARQ-ACK within a span of one PUCCH slot (both single carrier and UL CA), 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 the PUSCH.

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| UE procedure for reporting control information <unchanged text omitted>A UE does not expect to detect a DCI format scheduling a PDSCH reception or a SPS PDSCH release,a DCI format 1\_1 indicating Scell dormancy, or a DCI format including a One-shot HARQ-ACK request field with value 1, and indicating a resource for a PUCCH transmission with corresponding HARQ-ACK information in a slot if the UE previously detects a DCI format scheduling a PUSCH transmission in the slot and if the UE multiplexes HARQ-ACK information in the PUSCH transmission.If a UE transmits one 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 and the UE does not determine any PUCCH carrying HARQ-ACK information in the slot, the UE multiplexes HARQ-ACK information in the PUSCH transmission. |

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| 9.1.2.1 Type-1 HARQ-ACK codebook in physical uplink control channel <unchanged text omitted>A UE determines  HARQ-ACK information bits, for a total number of  HARQ-ACK information bits, of a HARQ-ACK codebook for transmission in a PUCCH or a PUSCH according to the following pseudo-code. In the following pseudo-code, if the UE does not receive a transport block or a CBG, due to the UE not detecting a corresponding DCI format 1\_0 or DCI format 1\_1, the UE generates a NACK value for the transport block or the CBG. The cardinality of the set  defines a total number  of occasions for PDSCH reception or SPS PDSCH release for serving cell  corresponding to the HARQ-ACK information bits.<unchanged text omitted> |

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| 9.1.3.1 Type-2 HARQ-ACK codebook in physical uplink control channel <unchanged text omitted>If the UE transmits HARQ-ACK information in a PUSCH or a PUCCH in slot  with reference to slots for PUCCH transmission  and for any PUCCH format, the UE determines the , for a total number of  HARQ-ACK information bits, according to the following pseudo-code:<unchanged text omitted> |

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| **Company** | **Comments** |
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###  Issue 2-2: CR cover page

This proposal is based on an update from the version in R1-2204554 [5]. Please review for correctness whether or not you support this or not.

**Consequences if not approved:**

* This CR completes an incompletely specified Rel-15 functionality for multiplexing HARQ-ACK in a PUSCH in a PUCCH slot when the UE misses any HARQ-ACK to transmit in any PUCCH but receives UL grant(s) with UL-TDAI field to transmit a single PUSCH or multiple PUSCHs in the PUCCH slot.A UE implemented based on an earlier version of the specification, and for case of multiple PUSCHs not able to indicate the new UE capability, may still be compliant with this CR, while a UE not compliant with the CR has unknown behavior. See isolated impact analysis.

**Isolated impact analysis**

* If a gNB is implemented according to the CR, but the UE is not, the UE behavior is unclear when HARQ-ACK is to be multiplexed in a PUSCH on a PUCCH slot where the UE transmits one or more PUSCHs scheduled by UL grant(s) with UL-TDAI in the PUCCH slot on one or more than 1 carrier, potentially leading to loss of UCI as well as loss of PUSCH.
* If the UE is implemented according to the CR, but the gNB is not, the gNB assumption on where it expects to find the UCI is unclear when HARQ-ACK is to be multilplexed in a PUSCH on a PUCCH slot where the UE transmits ne or more PUSCHs scheduled by UL grant(s) with UL-TDAI in the PUCCH slot on one or more than 1 carrier, potentially leading to loss of UCI as well as loss of PUSCH.

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| **Company** | **Comments** |
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###  Issue 2-3: TP for Alt 1 proposal

This proposal is based on an update from the version in R1-2204554 [5]. We will work on the TPs in parallel with the general agreement. Please review for correctness whether or not you support this or not.

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| UE procedure for reporting control information<unchanged text omitted>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 transmission and the multiple PUSCHs overlap in the slot with a PUCCH carrying HARQ-ACK information or at least one of the multiple PUSCHs is scheduled by a DCI format that includes a DAI field, the UE determines the PUSCH for UCI multiplexing by applying the following procedure:* If the ~~a UE transmits~~ multiple PUSCHs ~~in a slot on respective serving cells that include~~ 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 multiple PUSCHs, and the multiple 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 ~~If a UE transmits multiple PUSCHs in a slot on respective serving cells and~~ the UE would multiplex UCI in one of the multiple PUSCHs and the UE does not multiplex aperiodic CSI in any of the multiple 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.
* If the UE does not determine any PUCCH carrying HARQ-ACK information in the slot and the UCI includes HARQ-ACK information due to a DAI field in a DCI format scheduling at least one the multiple PUSCHs, the UE multiplexes the UCI in the PUSCH if the UE indicates the corresponding capability [the name of the capability].

<unchanged text omitted> |

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| **Company** | **Comments** |
| NTT DOCOMO | We think the following part is new UE behavior and thus not aligned with section 2.1.5/2.1.6. We do not support this TP.‘If ... and the UCI includes HARQ-ACK information due to a DAI field in a DCI format scheduling at least one the multiple PUSCHs, the UE multiplexes the UCI in the PUSCH ...’In our understanding, current spec does not define UE behavior when UL grant corresponding to the selected PUSCH to multiplex HARQ-ACK indicates not to multiplex HARQ-ACK. Thus we think the following text is aligned with section 2.1.5/2.1.6.‘If ... and the UCI includes HARQ-ACK information due to a DAI field in a DCI format scheduling the PUSCH, the UE multiplexes the UCI in the PUSCH ...’ |

###  Issue 2-4: TP for Alt 2 proposal

This proposal is based on an update from the FL based on a version in R1-2204554 [5]. We will work on the TPs in parallel with the general agreement. Please review for correctness whether or not you support this or not.

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| UE procedure for reporting control information<unchanged text omitted>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 transmission and the multiple PUSCHs overlap in the slot with a PUCCH carrying HARQ-ACK information or at least one of the multiple PUSCHs is scheduled by a DCI format that includes a DAI field, the UE determines the PUSCH for UCI multiplexing by applying the following procedure:* If the ~~a UE transmits~~ multiple PUSCHs ~~in a slot on respective serving cells that include~~ 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 multiple PUSCHs, and the multiple 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 ~~If a UE transmits multiple PUSCHs in a slot on respective serving cells and~~ the UE would multiplex UCI in one of the multiple PUSCHs and the UE does not multiplex aperiodic CSI in any of the multiple 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.
* If the UE does not determine any PUCCH carrying HARQ-ACK information in the slot and the UCI includes HARQ-ACK information due to a DAI field in a DCI format scheduling at least one the multiple PUSCHs PUSCHs without UL-TDAI=4 in case Type 2 CB, and without UL-TDAI n.e. 1 in case of Type 1 CB, the UE multiplexes the UCI in the PUSCH if the UE indicates the corresponding capability [the name of the capability].

<unchanged text omitted> |

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| **Company** | **Comments** |
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### Issue 3: Repetition

A few companies continued the discussion on HARQ-ACK multiplexing without PUCCH with repetition:

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| ZTE [2] | *Proposal 2: One of the PUSCH repetitions should be specified for HARQ-ACK multiplexing if the UE does not know the overlapping PUCCH slot due to missing detection of the DL DCI and 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.* |
| Ericsson/Nokia [5] | *When a PUSCH scheduled by DCI is repeated and the corresponding UL grant indicates UL-TDAI but a PUCCH with HARQ-ACK is absent throughout the PUSCH repetition, the first PUSCH of the repetition is considered as a candidate PUSCH for HARQ-ACK multiplexing following the unified solution.* |
| Intel [6] | *Proposal 3: For PUSCH repetition case, 1st PUSCH repetition within a PUCCH slot is selected for HARQ-ACK multiplexing.*  |
| CATT [3] | *Otherwise if the selected PUSCH is with repetition, UE does not multiplex HARQ-ACK in the selected PUSCH repetition.* |
| Nokia from [14] | *If we adopt Alt 2 (due to inability to agree to a standard) we need to be clear that the standard does not support UL CA and PUSCH repetition.*  |

In summary, we have the following positions from the contributions this meeting:

* **Alt 3-1: 1st PUSCH repetition within PUCCH slot is selected :** ZTE, Ericsson, Nokia, Intel
	+ **Advantage: proponents say that this ensures a well-defined UE behavior. Note that network would need to schedule PUCCH resource by the time PUSCH is scheduled i.e. UE needs to know PUCCH resource at time DCI for PUSCH is received.**
* **Alt 3-2: UE does not multiplex HARQ-ACK in any of the PUSCH repetitions:** CATT
	+ **Advantage: proponents say that this option follows the agreement in RAN1 #94 for slot-level case as shown below:**

RAN1#94 meeting:

Agreements**:**

* The UE multiplexes HARQ-ACK in any slot of a multi-slot PUSCH transmission where the UE would otherwise transmit HARQ-ACK in a single slot PUCCH transmission, based on the HARQ timeline
* DAI is applicable in any slot where the UE would transmit HARQ-ACK

Note that if there is no consensus, the fallback position would be to accept Nokia’s suggestion that there is no simultaneous support for UL CA and PUSCH repetition.

###  Proposal 1: Repetition for Rel-15 Ues

For a Rel. 15 UE, when a PUSCH scheduled by DCI is repeated and the corresponding UL grant indicates UL-TDAI but a PUCCH with HARQ-ACK is absent throughout the PUSCH repetition, the UE behavior is up to UE implementation

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| **Company** | **Comments** |
| NTT DOCOMO | OK |
| LG | OK |
| MTK | OK |

# 1st Round Summary

# Conclusions

# References

1. R1-2203104 Discussion on HARQ-ACK multiplexing on PUSCH without PUCCH, Huawei/Hi-Silicon RAN1 #109-e
2. R1-2203182 Discussion on HARQ-ACK multiplexing on PUSCH, ZTE, RAN1 #109-e
3. R1-2203415 Discussion on HARQ-ACK multiplexing in PUSCH without PUCCH CATT, RAN1 #109-e
4. R1-2204196 On Remaining Issues for PUSCH UCI Multiplexing without HARQ-ACK Apple, RAN1 #109-e
5. R1-2204554 HARQ-ACK multiplexing on PUSCH without PUCCH Ericsson, Nokia/NSN, RAN1 #109-e
6. R1-2204760 Discussion on HARQ-ACK multiplexing on PUSCH, Intel, RAN1 #109-e
7. 3GPP TS 38.213, v15.13.0.
8. R1-1907441, Multiplexing of overlapping PUCCH and PUSCH with different numerologies, Nokia, RAN1 #97
9. R1-2106327, Summary for [105-e-NR-7.1CRs-02] Discussions on PUSCH UCI Multiplexing without HARQ-ACK PUCCH, Moderator (Apple), RAN1 #105-e
10. Chairman’s Notes, RAN1 #106-e
11. R1-2108647, Summary for [106-e-NR-7.1CRs-07] Discussion on HARQ-ACK multiplexing on PUSCH without PUCCH, Apple (Moderator), RAN1 #106-e
12. Chairman’s Notes, RAN1 #107-e
13. R1-2112859, Summary for [107-e-NR-7.1CRs-6] Issue #10 Discussion on HARQ-ACK multiplexing on PUSCH, Moderator (Apple), RAN1 #107-e
14. R1-2202835, Summary for [108-e-NR-CRs-06] Issue #8: Discussion on HARQ-ACK multiplexing on PUSCH, Moderator (Apple)

# Appendix: Background

### PUCCH Prioritization Rules for Rel-15:

In the case of overlapping PUCCH resources and PUSCHs, determination of whether or not the UE multiplexes information in a PUSCH transmission was discussed in the following conclusion in RAN1 #97[9][10]:

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| **conclusion** For the issue raised in the draft CR [R1-1906302](https://www.3gpp.org/Users/komeoteri/Documents/3GPP/Meetings/2021%20April%20RAN1%20%20104bis-e%20Meeting/Docs/R1-1906302.zip), the intended UE behavior per specification is commonly understood as follows:* For UCI multiplexing, within a PUCCH group, on PUSCH, the following two steps are performed with step 1 first, then followed by step 2:
	+ Step 1: UCI in overlapped PUCCH transmissions is multiplexed into one PUCCH resource (resource Z). This step is done per PUCCH slot.
	+ Step 2: UCI, that doesn’t include SR, in Z is multiplexed into one PUSCH, if Z overlaps with at least one PUSCH, following the priorities (sequentially from high to low) as listed below.
		- First priority: PUSCH with A-CSI as long as it overlaps with Z
		- Second priority: earliest PUSCH slot(s) based on the start of the slot(s)
		- If there are still multiple PUSCHs overlap with Z in the earliest PUSCH slot(s), follow the following priorities (sequentially from high to low)
			* Third priority: Dynamic grant PUSCHs > PUSCHs configured by respective ConfiguredGrantConfig or semiPersistentOnPUSCH
			* Fourth priority: PUSCHs on serving cell with smaller ~~CC~~ serving cell index > PUSCHs on serving cell with larger serving cell index
			* Fifth priority: Earlier PUSCH transmission > later PUSCH transmission

Note: The clarification applies to both cases with the same (except the second priority part) and different numerologies among PUCCH and PUSCHs. |

The UCI multiplexing on PUCCH is specified in Section 9.2.5 of [7] and the PUSCH prioritization rule for UCI multiplexing on PUSCH is specified in Section 9 of [7]:

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| **PUSCH prioritization rule for HARQ-ACK multiplexing (Clause 9 of TS 38.213)** If a UE transmits multiple PUSCHs in a slot on respective serving cells that 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 multiple PUSCHs, and the multiple 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 a UE transmits multiple PUSCHs in a slot on respective serving cells and the UE would multiplex UCI in one of the multiple PUSCHs and the UE does not multiplex aperiodic CSI in any of the multiple 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. 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 HARQ-ACK 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. |

# Appendix: Contribution Proposals

The following proposals have been made in the contributions:

### Huawei: R1-2203104 [1]

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| ***Proposal 1: In case of more than one non-overlapping PUSCHs without PUCCH within a span on one PUCCH slot (both single carrier and UL CA), if more than one PUSCHs with UL-TDAI not equal to 4 (for Type 2 codebook) or equal to 1 (for Type 1 codebook), UE selects one PUSCH to multiplex following the rules:**** ***Selection of the candidate PUSCH for multiplexing***
	1. ***PUSCHs without UL-TDAI=4 in case Type 2 CB, and without UL-TDAI n.e. 1 in case of Type 1 CB within the PUCCH slot are candidates***
	2. ***The DAI field value of multiple PUSCH(s) should be the same***
* ***Prioritization rules to select PUSCH for multiplexing. Prioritization rules are identical to 38.213.***
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###  ZTE R1-2203182 [2]

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| ***Proposal 1:*** *Option 1 with Alt-2 should be adopted.** *For multiple PUSCHs in a slot, the UE should perform HARQ-ACK multiplexing in the PUSCH with DAI equal to 1 for Type 1 codebook or not equal 4 for Type 2 codebook. If there are more than one such PUSCHs, the UE should select the PUSCH for HARQ-ACK multiplexing from these PUSCHs according to the current PUSCH prioritization rule.*

***Proposal 2:*** *One of the PUSCH repetitions should be specified for HARQ-ACK multiplexing if the UE does not know the overlapping PUCCH slot due to missing detection of the DL DCI and 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.* |

###  CATT : R1-2201755 [3]

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| **Proposal: For one or multiple PUSCHs and no PUCCH with HARQ-ACK within a span of one PUCCH slot, UE selects one PUSCH from the PUSCHs with UL-TDAI not equal to 4 (for Type 2 codebook) or equal to 1 (for Type 1 codebook), if any, according to the PUSCH selection rule defined in TS39.213 Clause 9.** * **If none of the PUSCHs is with UL-TDAI not equal to 4 (for Type 2 codebook) or equal to 1 (for Type 1 codebook), UE does not multiplex HARQ-ACK in any PUSCH;**
* **Otherwise if the selected PUSCH is not with repetition, UE multiplexes HARQ-ACK in the selected PUSCH according to the UL-TDAI for the selected PUSCH;**
* **Otherwise if the selected PUSCH is with repetition, UE does not multiplex HARQ-ACK in the selected PUSCH repetition.**
* **Note: it is up to gNB to decide whether to set the same UL-TDAI for all the PUSCHs overlapping with a same HARQ-ACK.**
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###  Apple R1-2204196 [4]

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| ***Proposal 1:*** *For Rel-16 UEs, introduce a virtual PUCCH, select candidate UEs based on the virtual PUCCH and reuse the multiplexing procedure in Rel-15.* ***Proposal 2:*** *This can be captured by the following:*1. *Selection of the candidate PUSCH for multiplexing*
	1. ***Alt-1:*** *All the PUSCHs within the PUCCH slot are candidates*
	2. ***Alt-2:*** *PUSCHs without UL-TDAI=4 in case Type 2 CB, and without UL-TDAI n.e. 1 in case of Type 1 CB within the PUCCH slot are candidates*
	3. *N/W sets all TDAI values that overlap with PUCCH to the [same/****differen****t] value with TDAI n.e. 4*
2. *Prioritization rules to select PUSCH for multiplexing. Prioritization rules are identical to 38.213*
3. *Limitations for multiplexing*
	1. *UE expects to multiplex HARQ-ACK on only 1 PUSCH in the PUCCH slot.*
	2. *All the PUSCHs in the determined candidate set after step 1 have to satisfy Rel-15 UCI multiplexing timeline, defined with respect the starting symbol of the earliest PUSCH transmission in the candidate set****.***
4. *For item 1.a and 1.b, RAN1 can select either Alt-1 or Alt-2 with a slight preference for Alt-1*
5. *For item 1.c, RAN1 should allow the network to set the TDAI values that overlap with the PUCCH to* ***different*** *values when TDAI n.e. 4*
6. *To mitigate the effect of the agreement on already implemented UEs, a* ***UE capability*** *may be introduced to indicate to the gNB if the UE implements the procedure.*

*NOTE: This does not over-ride the agreements made in RAN1 #107-e and RAN1#108-e.* |

### Ericsson/Nokia/NSN R1-2204554 [5]

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| 1. Aiming for a unified solution including the multiple PUSCHs cases is crucial to not compromise the performance of UL CA deployments.
2. Different solutions for Rel16 and Rel-17 should be avoided. The NW would behave according to the specified behavior and does not change its behavior for this feature whether the UE indicates Rel-15/16/17, etc.
3. The unified solution to specify behavior for the case that PUCCH is absent should not diverge from the specified behavior when a PUCCH would be present. Any optimization is matter of implementation and not specification.
4. Introduction of capability for the solution can ease the UE implementations concern. While the earliest the behaviour is specified and implemented by UEs, improves the system performance due to less UEs with unknown behaviour in the NW.

[Proposal 1 For the case when multiple PUSCHs with no overlapping PUCCH with HARQ-ACK within a span of one PUCCH slot, the corresponding UE behavior is subject to indicating a capability and specified based on the following procedures (i.e. Option 1 with Alt-1 and no constraint on UL-TDAI):](#_Toc101723648)[Proposal 2 Adopt the following Text proposals and corresponding descriptions for consequences and inter-operability analysis to implement the agreement for single PUSCH case as well as the proposal for multiple PUSCHs case for Rel-16 CR (being mirrored to Rel-17 CR)](#_Toc101723649)[Proposal 3 When a PUSCH scheduled by DCI is repeated and the corresponding UL grant indicates UL-TDAI but a PUCCH with HARQ-ACK is absent throughout the PUSCH repetition, the first PUSCH of the repetition is considered as a candidate PUSCH for HARQ-ACK multiplexing following the unified solution.](#_Toc101723650) |

### Intel R1-2204760 [6]

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| **Proposal 1: To select the candidate PUSCH for multiplexing, PUSCHs without UL-TDAI=4 in case Type 2 CB, and without UL-TDAI n.e. 1 in case of Type 1 CB within the PUCCH slot are candidates, and N/W sets all TDAI values that overlap with PUCCH to the same value with TDAI n.e. 4.** **Proposal 2: RAN1 to clarify that PUSCHs within a PUCCH slot includes PUSCHs overlapping with the PUCCH slot.** * **If the UE identifies more than one PUCCH with HARQ-ACK to be multiplexed in the same PUSCH due to uncertainty of miss-detected PUCCH, UE only multiplexes HARQ-ACK from one PUCCH onto the PUSCH.**

**Proposal 3: For PUSCH repetition case, 1st PUSCH repetition within a PUCCH slot is selected for HARQ-ACK multiplexing.** **Proposal 4: If a UE fails to receive any PDCCH for a PUCCH with HARQ-ACK in a PUCCH slot, UE multiplexes CSI in the same PUSCH for HARQ-ACK.**  |