**3GPP TSG RAN WG1 Meeting #107-e R1-211xxxx**

**e-Meeting, August 16th – 27th, 2021**

**Source: Moderator (Apple)**

**Title: Summary for [107-e-NR-7.1CRs-6] Issue #10: Discussion on HARQ-ACK multiplexing on PUSCH**

**Agenda item: 7.1**

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

# Introduction

This document provides the summary for the following email discussion in RAN1#107-e:

[107-e-NR-7.1CRs-6] Issue#10: Discussion on HARQ-ACK multiplexing on PUSCH without PUCCH with contributions [1], [2], [3], [4], ,[5] (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 behaivor as follows [6], [8]:

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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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For Rel-16 UE behavior, the following options are under discussion:

* ***Alt #1****: in the case of multiple overlapping PUSCHs with no overlapping PUCCH, and if UL-TDAI n.e. 4 (for Type 2 codebook) or UL-TDAI e.g. 1 (for Type 1 codebook) the UE does not multiplex HARQ-ACK information in any PUSCH.*
* **Alt #3-2**: *in the case of multiple overlapping PUSCHs with no overlapping PUCCH, and if UL-TDAI n.e. 4 (for Type 2 codebook) or UL-TDAI e.g. 1 (for Type 1 codebook) the UE selects a PUSCH and multiplexes HARQ-ACK information in the PUSCH according to the indicated value of DAI field in DCI format 0\_1.*
	+ *Follow the tDAI in the lastly received UL grant for the group to multiplex HARQ-ACK on the PUSCH scheduled by the lastly received UL grant, and ignore the tDAIs in other UL grants scheduling other PUSCHs in the group.*
* **Alt #3-3**: *in the case of multiple overlapping PUSCHs with no overlapping PUCCH, and if UL-TDAI n.e. 4 (for Type 2 codebook) or UL-TDAI e.g. 1 (for Type 1 codebook) the UE selects a PUSCH and multiplexes HARQ-ACK information in the PUSCH according to the indicated value of DAI field in DCI format 0\_1.*
	+ *Select one PUSCH within multiple PUSCH with DAI=1 following the same PUSCH prioritization rules for UCI multiplexing with PUCCH for type-1 HARQ-ACK codebook.*
	+ *Select one PUSCH within multiple PUSCH with DAI≠4 following the same PUSCH prioritization rules for UCI multiplexing with PUCCH for type-2 HARQ-ACK codebook*
	+ *PUSCH selection method:****The DAI field value of multiple PUSCH should be the same.***

and company positions as follows:

##### Recommendation 5: Down-select Alt 3-1 as there is only one company supporting this with many companies against.

* *Alt 1: Samsung, MTK, Vivo, CATT, Apple, Intel, Spreadtrum, NTT DOCOMO (1st Choice), , Lenovo (2nd choice) (9 companies, 8 1st choice companies)*
	+ *Against: Huawei, Qualcomm, Ericsson, ZTE*
* *Alt 3-2: Qualcomm, Ericsson (2nd choice), ZTE, Lenovo, Nokia/NSB (5 companies)*
	+ *Against: NTT DOCOMO, CATT, Samsung, MTK, Apple*
* *Alt 3-3: Ericsson (1st choice), Huawei, NTT DOCOMO, CATT (2nd choice), ZTE, Nokia/NSB (6 companies)*
	+ *Against: Qualcomm, Samsung, MTK, Apple*
* *NOTE: Alt 3: ZTE, Qualcomm, Nokia/NSB, Huawei, Ericsson, Lenovo (1st choice), NTT DOCOMO (2nd choice), CATT (2nd choice) (8 companies, 7 1st choice companies)*

At the end of the meeting, the chairman’s concluded that we should continue the discussion for Rel-16 in RAN1#107-e. A detailed background on the issue can be found in the Appendix in Section 4.

# 1st Round

### Rel-16 UEs with Multiple Overlapping PUSCHs

In the case of multiple overlapping PUSCHs with overlapping PUCCH, the understanding is that the UE uses PUSCH prioritization rules to select a PUSCH and multiplexes HARQ-ACK information in the PUSCH according to the indicated value of DAI field in DCI format 0\_1. This means that the UE would multiplex on at most one PUSCH. However, if the UE misses the DL DCI, then the UE behavior needs to be clarified. To assist in the discussion, the following example could be used. In the example, the UE misses the DL DCI and its associated PUCCH. On CC1, the UL TDAI can be set to X where X = 4 or X = {1, 2 or 3} while on CC2, UL DCI2 is set to 1.



Figure 1: HARQ-ACK Transmission with overlapping PUSCH and no PUCCH

Based on the contributions in this meeting and the positions from the last meeting, we can identify the following alternatives for discussion.

Please indicate (1) preferred alternative and corresponding pros (2) objections to any alternatives and corresponding cons from the following alternatives:

* ***Alt #1****: in the case of multiple overlapping PUSCHs with no overlapping PUCCH, and if UL-TDAI n.e. 4 (for Type 2 codebook) or UL-TDAI e.g. 1 (for Type 1 codebook) the UE does not multiplex HARQ-ACK information in any PUSCH.*
	+ *Apple [3]*
* **Alt #3-2**: *in the case of multiple overlapping PUSCHs with no overlapping PUCCH, and if UL-TDAI n.e. 4 (for Type 2 codebook) or UL-TDAI e.g. 1 (for Type 1 codebook) the UE selects a PUSCH and multiplexes HARQ-ACK information in the PUSCH according to the indicated value of DAI field in DCI format 0\_1.*
	+ *Follow the tDAI in the lastly received UL grant for the group to multiplex HARQ-ACK on the PUSCH scheduled by the lastly received UL grant, and ignore the tDAIs in other UL grants scheduling other PUSCHs in the group.*
	+ *ZTE [1], Nokia[2], Huawei[3]*
* **Alt #3-3**: *in the case of multiple overlapping PUSCHs with no overlapping PUCCH, and if UL-TDAI n.e. 4 (for Type 2 codebook) or UL-TDAI e.g. 1 (for Type 1 codebook) the UE selects a PUSCH and multiplexes HARQ-ACK information in the PUSCH according to the indicated value of DAI field in DCI format 0\_1.*
	+ *Select one PUSCH within multiple PUSCH with DAI=1 following the same PUSCH prioritization rules for UCI multiplexing with PUCCH for type-1 HARQ-ACK codebook.*
	+ *Select one PUSCH within multiple PUSCH with DAI≠4 following the same PUSCH prioritization rules for UCI multiplexing with PUCCH for type-2 HARQ-ACK codebook*
	+ *PUSCH selection method:* ***The DAI field value of multiple PUSCH should be the same.***
* **Alt #4**: *For the issue of HARQ-ACK multiplexing on a group of PUSCHs without HARQ-ACK PUCCH, the conclusion made for Rel-15 is applied to Rel-16.*
	+ *Qualcomm [5]*

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| **Company** | **Comments** |
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### Rel-16 UEs with a single PUSCH

From the discussion in RAN1 #106-e, RAN1 has common understanding between companies that our goal is the same solution for single and multiple PUSCH scenarios but no agreement that the solutions have to be the same. Based on the contributions in this meeting and the positions from the last meeting, we can identify the following alternatives for discussion.

Please indicate (1) preferred alternative and corresponding pros (2) objections to any alternatives and corresponding cons from the following alternatives:

* ***Alt #1****: in the case of a single PUSCH with no overlapping PUCCH, and if UL-TDAI n.e. 4 (for Type 2 codebook) or UL-TDAI e.g. 1 (for Type 1 codebook) the UE does not multiplex HARQ-ACK information in any PUSCH.*
* **Alt #3-3**: *in the case of a single PUSCH with no overlapping PUCCH, and if UL-TDAI n.e. 4 (for Type 2 codebook) or UL-TDAI e.g. 1 (for Type 1 codebook) the UE should perform HARQ-ACK multiplexing in the PUSCH with the assumption that PUCCH resource for HARQ-ACK information overlaps with the PUSCH in the time domain****.***
	+ *ZTE[1], Nokia [2], [3]*
* **Alt #4**: *For the issue of HARQ-ACK multiplexing on a single of PUSCHs without HARQ-ACK PUCCH, the conclusion made for Rel-15 is applied to Rel-16.*

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| **Company** | **Comments** |
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### Specification Clarification

In RAN1 #106-e, a controversial point in the specificaiton was identified based on the following specification text:

*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.*

Please indicate your interpretation:

* Interpretation 1: multiple PUSCHs overlapping with the PUCCH shall have the same UL DAI
* Interpretation 2: multiple PUSCHs overlapping with the PUCCH may have different UL DAI
* Interpretation 3: any other interpretation

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| **Company** | **Comments** |
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# Summary of 1st Round

# References

1. R1-2111361 Discussion on HARQ-ACK multiplexing on PUSCH ZTE, RAN1 #107-e
2. R1-2111784 HARQ-ACK muxing on PUSCH without PUCCH Nokia, Nokia Shanghai Bell, RAN1 #107-e
3. R1-2111847 Discussions on PUSCH UCI Multiplexing without HARQ-ACK PUCCH Apple, RAN1 #107-e
4. R1-2111920 Discussion on the UCI multiplexing without PUCCH Huawei, HiSilicon, RAN1 #107-e
5. R1-2112192 Discussion on HARQ-ACK multiplexing on PUSCH without PUCCH Qualcomm Incorporated, RAN1 #107-e
6. R1-2108647, Summary for [106-e-NR-7.1CRs-07] Discussion on HARQ-ACK multiplexing on PUSCH without PUCCH, Apple (Moderator)
7. 3GPP TS 38.213, v15.13.0.
8. Chairman’s Notes, RAN1 #106-e
9. R1-1907441, Multiplexing of overlapping PUCCH and PUSCH with different numerologies, Nokia, RAN1 #97
10. R1-2106327, Summary for [105-e-NR-7.1CRs-02] Discussions on PUSCH UCI Multiplexing without HARQ-ACK PUCCH, Moderator (Apple), RAN1 #105-e

# Appendix: Background

### Type 1 HARQ ACK Codebook

In Section 9.1.2.2 of [7], it is specified that a UE multiplexes HARQ-ACK information in a PUSCH transmission scheduled by DCI format 0\_1 when the DAI field in DCI format 0\_1 is set to ‘1’ (which is corresponding to ).

#### 9.1.2.2 Type-1 HARQ-ACK codebook in physical uplink shared channel

If a UE multiplexes HARQ-ACK information in a PUSCH transmission that is scheduled by DCI format 0\_1, the UE generates the HARQ-ACK codebook as described in Clause 9.1.2.1 when a value of the DAI field in DCI format 0\_1 is  except that *harq-ACK-SpatialBundlingPUCCH* is replaced by *harq-ACK-SpatialBundlingPUSCH*. The UE does not generate a HARQ-ACK codebook for multiplexing in the PUSCH transmission when  unless the UE receives only a SPS PDSCH release, or only a SPS PDSCH, or only a PDSCH that is scheduled by DCI format 1\_0 with a counter DAI field value of 1 on the PCell in the  occasions for candidate PDSCH receptions in which case the UE generates HARQ-ACK information only for the SPS PDSCH release or only for the PDSCH reception as described in Clause 9.1.2.  if the DAI field in DCI format 0\_1 is set to '0'; otherwise, .

The spirit of HARQ-ACK information feedback is that a UE generates and feedbacks ACK/NACK information to let network know whether the SPS PDSCH release or the transport block is successfully received or not. It should be clarified whether the value of DAI field in DCI format 0\_1 is allowed to be for Type 1 codebook (or  for Type 2 codebook) if the network does not transmit any DL DCI/PDSCH. The purpose of such indication is not clear and may lead to meaningless HARQ-ACK information feedback.

On the other hand, if the network has the freedom to assign any value of DAI field regardless of whether there is DL DCI/PDSCH or not, then the corresponding UE behavior is ambiguous. Two possible interpretations are as follows.

* **Interpretation #1**: the UE does not multiplex HARQ-ACK information in a PUSCH since there is no DL DCI/PDSCH received.
* **Interpretation #2:** the UE multiplexes HARQ-ACK information in a PUSCH according to the indicated value of DAI field in DCI format 0\_1.

In Section 9.1.2.2 of [3], it says that a UE generates HARQ-ACK codebook as described in Clause 9.1.2.1 ***IF*** a UE multiplexes HARQ-ACK information in a PUSCH transmission. ***Then, in this case, it is not clear whether the UE needs to generate HARQ-ACK information if there is no DL DCI/PDSCH received.***

## 9.1 HARQ-ACK codebook determination

If a UE receives a PDSCH without receiving a corresponding PDCCH, or if the UE receives a PDCCH indicating a SPS PDSCH release, the UE generates one corresponding HARQ-ACK information bit.

If a UE is not provided *PDSCH-CodeBlockGroupTransmission*, the UE generates one HARQ-ACK information bit per transport block.

For a HARQ-ACK information bit, a UE generates an ACK if the UE detects a DCI format 1\_0 that provides a SPS PDSCH release or correctly decodes a transport block, and generates a NACK if the UE does not correctly decode the transport block.

### Type 2 HARQ ACK Codebook

In Section 9.1.3.2 of [7], the UE behavior for Type-2 HARQ-ACK codebook in PUSCH is specified as follows:

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| If a UE would multiplex HARQ-ACK information in a PUSCH transmission that is not scheduled by a DCI format or is scheduled by DCI format 0\_0, then- if the UE has not received any PDCCH within the monitoring occasions for DCI format 1\_0 or DCI format 1\_1 for scheduling PDSCH receptions or SPS PDSCH release on any serving cell  and the UE does not have HARQ-ACK information in response to a SPS PDSCH reception to multiplex in the PUSCH, as described in Subclause 9.1.3.1, the UE does not multiplex HARQ-ACK information in the PUSCH transmission;- else, the UE generates the HARQ-ACK codebook as described in Subclause 9.1.3.1, except that *harq-ACK-SpatialBundlingPUCCH* is replaced by *harq-ACK-SpatialBundlingPUSCH*.If a UE multiplexes HARQ-ACK information in a PUSCH transmission that is scheduled by DCI format 0\_1, the UE generates the HARQ-ACK codebook as described in Subclause 9.1.3.1, with the following modifications:- For the pseudo-code for the HARQ-ACK codebook generation in Subclause 9.1.3.1, after the completion of the  and  loops, the UE sets  where  is the value of the DAI field in DCI format 0\_1 according to Table 9.1.3-2- For the case of first and second HARQ-ACK sub-codebooks, DCI format 0\_1 includes a first DAI field corresponding to the first HARQ-ACK sub-codebook and a second DAI field corresponding to the second HARQ-ACK sub-codebook*- harq-ACK-SpatialBundlingPUCCH* is replaced by *harq-ACK-SpatialBundlingPUSCH*.If a UE is not provided *PDSCH-CodeBlockGroupTransmission* and the UE is scheduled for a PUSCH transmission by DCI format 0\_1 with DAI field value  and the UE has not received any PDCCH within the monitoring occasions for PDCCH with DCI format 1\_0 or DCI format 1\_1 for scheduling PDSCH receptions or SPS PDSCH release on any serving cell  and the UE does not have HARQ-ACK information in response to a SPS PDSCH reception to multiplex in the PUSCH, as described in Subclause 9.1.3.1, the UE does not multiplex HARQ-ACK information in the PUSCH transmission.  |

### 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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| 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.  |

However, there may be scenarios in which the PUSCH UL-TDAI indicates HARQ-ACK bits are present but there is no DL DCI received by the UE indicating a PUCCH resource. As such, there is no PUCCH overlapping or colliding with the PUSCH(s). We would like to clarify the UE behavior in these cases.

# Appendix: Contribution Proposals

### ZTE: R1-2111361 [1]

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| ***Observation 1:*** *The purpose of the T-DAI in the UL DCI is to address the DL DCI missing such that the network and the UE have the same understanding on the UCI size.****Proposal 1:*** *RAN1 to clarify that a DL DCI cannot be transmitted after a UL DCI if the indicated PUCCH and PUSCH are overlapping in the same slot.* ***Proposal 2:*** *In Rel-16, if a UE detects a single PUSCH in a slot scheduled by a DCI with the indicated T-DAI value not equal to 0 for Type-1 codebook or 4 for Type-2 codebook, the UE should perform HARQ-ACK multiplexing in the PUSCH with the assumption that PUCCH resource for HARQ-ACK information overlaps with the PUSCH in the time domain.* ***Proposal 3:*** *For the scenario of more than one non-overlapping PUSCH in a slot, if UL T-DAI is not set to 4 for Type 2 codebook or is set to 1 for Type 1 codebook, the UE selects a PUSCH following the current PUSCH prioritization rule and multiplexes HARQ-ACK information in the selected PUSCH with the assumption that the PUCCH resource for the HARQ-ACK information overlaps with the selected PUSCH.*  |

### Nokia R1-2111784 [2]

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| For two or more overlapping PUSCH case the following observation and proposal is made:**Observation 1:** Due to lack of specification, with UL CA, the gNB cannot use the UL-TDAI mechanism to ensure that the PUSCH decoding process knows whether HARQ-ACK bits are muxed on the PUSCH, risking the correct decoding of PUSCH.**Proposal 1:** Specify that if two or more PUSCHs are transmitted, the UE has no HARQ-ACK information to multiplex on PUSCH, and HARQ-ACK bits are to be multiplexed on PUSCH due to UL-TDAI =1 (CB1) or UL-TDAI < 4 (CB2), then the PUSCH selection for the HARQ-ACK bits multiplexing follows the same procedure as defined for the case when the UE has HARQ-ACK information to multiplex on PUSCH.1. PUSCH with aperiodic CSI, if one is present
2. Dynamically scheduled PUSCH(s) prioritized over CG PUSCH(s)
3. PUSCH with smallest *ServCellIndex*

For one PUSCH case the following observation and proposal is made**Observation 2:** If the UE does not mux HARQ-ACK on PUSCH because it did not have any HARQ-ACK to transmit, regardless of the received UL-TDAI, it defeats the purpose of the UL-TDAI**Proposal 2:** Clarify that even if the UE has no HARQ-ACK information to multiplex on PUSCH, the UE shall multiplex HARQ-ACK bits on the PUSCH if* For HARQ-ACK CB1: UL-TDAI on the DCI scheduling the PUSCH is set to 1
* For HARQ-ACK CB2: UL-TDAI on the DCI scheduling the PUSCH is not set to 4
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### Apple : R1-2111847 [3]

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| ***Proposal 1:**** *For Rel-16 UEs, i****n the case of multiple overlapping PUSCHs with no overlapping PUCCH,*** *the UE does not multiplex HARQ-ACK information in any PUSCH since there is no DL DCI/PDSCH received overlapping PUCCH and PUSCH.*
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### Huawei R1-2111920 [4]

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| ***Proposal 1: For Rel-16, in case of single PUSCH without PUCCH, a UE multiplexes HARQ-ACK in PUSCH in the following cases**** ***For type-1 HARQ codebook, the UL DAI field is equal to 1***
* ***For type-2 HARQ codebook, the UL DAI filed is equal to 1/2/3***

***Observation 1: A UE cannot distinguish whether there is one single overlapping PUSCHs group or not according to UL DCI with DAI field value equal to 1 under the multiple DL DCI missing case, mixed numerology case, URLLC case.******Proposal 2: For Rel-16, in case of multiple overlapping PUSCHs with no overlapping PUCCH*** * ***Select one PUSCH within multiple PUSCH with DAI=1 following the same PUSCH prioritization rules for UCI multiplexing with PUCCH for type-1 HARQ-ACK codebook.***
* ***Select one PUSCH within multiple PUSCH with DAI≠4 following the same PUSCH prioritization rules for UCI multiplexing with PUCCH for type-2 HARQ-ACK codebook.***
	+ ***The DAI field value of multiple PUSCH should be the same***
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### Qualcomm R1-2112192 [5]

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| ***Proposal 1: For the issue of HARQ-ACK multiplexing on a group of PUSCHs without HARQ-ACK PUCCH, the conclusion made for Rel-15 is applied to Rel-16.***  |