**3GPP TSG RAN WG1 Meeting #106-e R1-210xxxx**

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

**Source: Moderator (Apple)**

**Title: Summary for [106-e-NR-7.1CRs-07] Discussion on 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#106-e:

[105-e-NR-7.1CRs-08] Issue#15: Discussion on HARQ-ACK multiplexing on PUSCH without PUCCH – Kome (Apple) with contributions [7],[8],[9],[10], and [11] (see the Appendix in Section 5 for a list of the proposals).

In RAN1 #105-e, there was a discussion on the topic with a summary of the status of the discussion, is as follows [6].:

(1) There was consensus to continue discussions for Rel-16 in next meeting.

(2) There is a discussion on the way forward for Rel-15:

* Option 1: Discuss in the next meeting - ZTE, CATT and Samsung
* Option 2: Declare that there is no consensus and leave to UE implementation - Qualcomm, MediaTek.

At the end of the meeting, the chairman’s concluded that we should continue the discussion for both Rel-15 and Rel-16 in RAN1#106-e. A detailed background on the issue can be found in the Appendix in Section 4.

# 1st Round

### Problem Statement

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.

Graphical user interface

Description automatically generated with medium confidence

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

### Rel-15 UEs Behavior

In the discussion during RAN1 #105-e, for a Rel-15 UE the following positions were taken:

* 11 companies **support** leaving this scenario to UE implementation: Oppo, QC, CATT, LG, Intel, Spreadtrum, MediaTek, Nokia, Apple, Ericsson, Huawei/HiSilicon
* 3 companies **do not support** leaving this scenario to UE implementation: Samsung, NTT DOCOMO, ZTE
* 1 company highlights that the  case of one PUSCH (no CA) vs multiple overlapping PUSCH (CA-case) needs clarification as well: Vivo

Based on the contributions to this meeting, the following are the current company positions:

* UE implementation: Qualcomm, NTT DOCOMO, Apple
* the UE does not multiplex HARQ-ACK information in any PUSCH since there is no overlapping PUCCH and PUSCH (Alt 1 from RAN1 #105-e): MediaTek
* 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 (Alt 3 from RAN1 #105-e): Huawei

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| **Position 1: UE implementation:** Qualcomm, NTT DOCOMO, Apple  Qualcomm [7]:  *Proposal 1: Without updating Rel-15 specification, leave it up to UE implementation to handle the case of HARQ-ACK multiplexing on a group of PUSCHs without HARQ-ACK PUCCH. RAN1 aim to find a solution for this case in Rel-16 specification.*  NTT Docomo [11]  Proposal 1:   * *In Rel-15, UE behavior in the situation illustrated in Fig.1 is not defined.*   Apple [10]:  *Proposal 1:*   * *For Rel-15 UEs, in the case of multiple overlapping PUSCHs with no overlapping PUCCH, the UE behavior is left to UE implementation.* |
| **Position 2: the UE does not multiplex HARQ-ACK information in any PUSCH since there is no overlapping PUCCH and PUSCH (Alt 1 from RAN1 #105-e):** MediaTek  MediaTek [8]  *Proposal 1: For both Rel-15 and Rel-16, when the value of DAI field in DCI format 0\_1 is for Type 1 HARQ-ACK codebook in PUSCH (or for Type 2 HARQ-ACK codebook in PUSCH), the UE does not multiplex HARQ-ACK information in any PUSCH if there is no overlapping PUCCH and PUSCH.* |
| **Position 3: 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 (Alt 3 from RAN1 #105-e):** ~~Huawei~~ |

Based on these inputs, please answer the following question:

#### Q1: . In the case of multiple overlapping PUSCHs with no overlapping PUCCH, what is the UE behavior in Rel-15?

* **Alt #1**: the UE does not multiplex HARQ-ACK information in any PUSCH since there is no overlapping PUCCH and PUSCH.
* **Alt #2:** the UE multiplexes HARQ-ACK information in a PUSCH if UL-TDAI n.e. 4 (for Type 2 codebook) or UL-TDAI e.q. 1 (for Type 1 codebook) in DCI Format 0\_1 otherwise it does not multiplex i.e. the UL UL-TDAI indicates which PUSCH to be multiplexed on.
* **Alt #3:** 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.
  + **Please detail rules to select PUSCH**
  + **NOTE: There are no PUSCH prioritization rules specified in Rel 15 without an overlapping PUCCH**
* **Alt #4:** This is left to UE implementation.

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| **Company** | **Comments** |
| ZTE | Our preference is Alt#2, while we are also ok with Alt#3.  Alt#1 is against the principle to define TDAI, and it would cause ambiguity at gNB side. Because gNB cannot be aware of whether the UE would miss the DCI. It would require gNB always perform blind decoding of PUSCH with or without UCI, regardless there is one or multiple overlapping PUSCHs.  Regarding Alt#3, the legacy PUSCH prioritization rules are applied. In case of non-CA case, no ambiguity would be caused. For CA case, it would have ambiguity between gNB and UE for the example shown in Figure 1. However, we can conclude such case, i.e., gNB should avoid a PUCCH only overlaps with some of the PUSCHs in the PUCCH slot. |
| QC | I expect we will repeat the same discussion in last meeting. At the end, different companies will have different interpretations of the spec for this case. For Rel-15, as many UEs/gNBs from different vendors are already deployed in the field, it is really impractical to introduce NBC change to spec. Therefore, we don’t see other way out of this issue rather than leaving this to UE implementation for Rel-15. |
| MTK | According to R15 current spec, from UE’s perspective there is no overlapping PUCCH and PUSCH. Hence, our preference is Alt. 1. |
| Nokia, NSB | We agree with the basic proposal of Huawei’s. There is no requirement for overlapping PUCCH and PUSCH for the UE to multiplex HARQ-ACK bits on PUSCH if the Vtdai so indicates. Our understanding is that this is intentional and covers the case where the PDSCH-scheduling DCI was lost.  It maybe so that due to lack of definition on which PUSCH to select for HARQ-ACK in Rel-15 we have no other choice but to leave Rel-15 up to UE implementation, but we would prefer agreeing to a rule. |
| vivo | We think the R15 current spec is clear and it is Alt 1. We can accept Alt 4 if different companies still have different interpretations of the spec for this case. As pointed by QC, many UEs/gNBs from different vendors are already deployed in the field, it is really impractical to introduce NBC change to spec. |
| NTT DOCOMO | Alt 4.  Of course agreeing a rule is our first preference. But at least for Rel-15, deciding rule would be impossible since companies have different views on UE behavior. In that sense, UE implementation is only the possible way. |
| CATT | Although we are open to discuss Alt #2, our understanding is that the current specification is aligned with Alt #1. |
| Lenovo, Motorola Mobility | Since Rel-15 UE are widely used now, any spec change is not preferred. So we think Alt 4 is the best choice so far. |
| Huawei, HiSilicon | There may be some misunderstanding. We agree with the analysis from QC that Alt#4 is probably the only choice for Rel-15. Alt#3 as proposed in our paper is intended for Rel-16.  For Alt#1, the DAI mechanism is introduced to solve the problem of UE missing DCI. And if the UE does not transmit UCI, the gNB may not decode the PUSCH successfully.  For Alt#2, it may cause multiple PUSCHs transmission carrying the same UCI simultaneously if multiple PUSCHs overlap with one PUCCH. |
| Intel | Although our understanding is Alt. 1 based on current specification, we understand this is for Rel-15 and it is expected that different UEs may have different implementations.  We are fine with Alt. 4 to leave UE implementation. |
| Samsung | We understand current situation. It is okay with alt. 4 if there is no common understanding in Rel-15. |
| Sharp | Current Rel-15 specification doesn’t specify any behavior for it. In that sense, introducing any UE behavior is NBC change. Therefore, we support Alt.4. |
| Ericsson | We share the same view as Nokia and HW/HiSi.  We understand any changes for Rel-15 is too late.  However, Huawei proposal is their contribution is aligned with our view and we would be supportive of that approach (Alt#3) for Rel-16. |
| Apple | We prefer Alt. 1. However, given the different interpretations we observed so far, we believe the only possible outcome would be to agree to Alt. 4 |
| Spreadtrum | Our preference is Alt 1. We can live with Alt 4. |
| Moderator | @ Huawei: We will make the correction to Huawei’s company position based on their comment. |

### Rel-16 UEs

In the discussion during RAN1 #105-e, for a Rel-16 UE the following positions were taken:

* Alt1: Oppo (2nd Choice), CATT, LG, Intel, Vivo, MediaTek, Apple (7)
* Alt 2:  Oppo (1st Choice), ~~NTT DOCOMO~~, ZTE (2)
* Alt 3: Qualcomm (Alt 4/5) (1)
* Question on CC Case: Qualcomm, Samsung (2)
* Discuss Next Meeting: Spreadtrum, Nokia, Ericsson, NTT DOCOMO, Huawei/HiSilicon (5)

Based on the contributions to this meeting, the following are the current company positions:

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| **Alt #1: the UE does not multiplex HARQ-ACK information in any PUSCH since there is no overlapping PUCCH and PUSCH:** MediaTek, NTT Docomo (Type 2 codebook only), Apple  MediaTek [8]  *Proposal 1: For both Rel-15 and Rel-16, when the value of DAI field in DCI format 0\_1 is for Type 1 HARQ-ACK codebook in PUSCH (or for Type 2 HARQ-ACK codebook in PUSCH), the UE does not multiplex HARQ-ACK information in any PUSCH if there is no overlapping PUCCH and PUSCH.*  NTT Docomo [11]  Proposal 2: *In Rel-16,*   * + *For Type 2 HARQ-ACK CB, UE does not multiplex HARQ-ACK on a PUSCH if the UE does not have a PUCCH transmission that is including HARQ-ACK and is overlapped with the PUSCH even when UL DAI corresponding to the PUSCH indicates HARQ-ACK multiplexing.*   + *For Type 1 HARQ-ACK CB, FFS.*   Apple [10]:  *Proposal 2: For Rel-16 UEs, in 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.* |
| **Alt #3: 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:** Qualcomm , Huawei  Qualcomm [7]:  *Proposal 2: In Rel-16 specification, solve the issue of HARQ-ACK multiplexing on a group of PUSCHs without HARQ-ACK PUCCH by taking one of the following options.*   * *Option 1: define a default/reference PUCCH resource, and use that default/reference PUCCH to start the UCI multiplexing procedure.* * *Option 2: 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.*   Huawei [9]:  *Proposal 2: 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* |

Based on these inputs, please answer the following question:

#### Q2: . In the case of multiple overlapping PUSCHs with no overlapping PUCCH, what is the UE behavior in Rel-16?

* **Alt #1**: the UE does not multiplex HARQ-ACK information in any PUSCH since there is no overlapping PUCCH and PUSCH.
* **Alt #2:** the UE multiplexes HARQ-ACK information in a PUSCH if UL-TDAI n.e. 4 (for Type 2 codebook) or UL-TDAI e.q. 1 (for Type 1 codebook) in DCI Format 0\_1 otherwise it does not multiplex i.e. the UL UL-TDAI indicates which PUSCH to be multiplexed on.
* **Alt #3:** 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.
  + **Please detail rules to select PUSCH**
  + **NOTE: There are no PUSCH prioritization rules specified in Rel 15 without an overlapping PUCCH**
* **Alt #4:** This is left to UE implementation.

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| **Company** | **Comments** |
| ZTE | Same as Q1, our preference is Alt#2, while we are also ok with Alt#3. |
| QC | Our understanding is current Rel-16 spec does not define a UE behavior for this case. So our interpretation of current RAN16 spec is Alt 4. But we think for Rel-16, RAN1 should define a reasonable UE behavior for this case.  Based on the above, in general, we agree with the spirit of Alt 3, although the details on how to select **THE** PUSCH for multiplexing can be further discussion. For Alt 1, it is against the purpose to introduce UL DAI so it does not make sense to us. For Alt 2, it requires UE to do replicate multiplexing on every PUSCH, it creates unnecessary complexity to UE and degrades PUSCH performance. |
| MTK | According to R16 current spec, from UE’s perspective there is no overlapping PUCCH and PUSCH. Hence, our preference is Alt. 1. We are not sure what’s the difference between R15 & R16 spec so there should be different UE behaviors. |
| Nokia, NSB | We do agree with the Qualcomm assessment of the current situation.  If we can’t agree on the PUSCH selection rule for Rel-15, then we could still do that for Rel-16 and that could lead to a different way of 3GPP handling of Rel-15 and Rel-16. |
| vivo | According to R16 current spec, it is Alt1. For Rel-15, considering that many UEs/gNBs from different vendors are already deployed in the field, we can compromise to Alt 4. But for Rel-16, we think the current spec does not need any change for Alt 1. To align companies’ understanding, a conclusion is enough. Both alt 2 and alt 3 have to change the current spec. |
| NTT DOCOMO | Our first preference is Alt 1. Alt 4 is acceptable.  Alt 3 would need large specification efforts, which is not good in CR phase. (We do not prefer the situation of discussions for PUSCH DG skip...)  One note is that in type 2 HARQ-ACK CB, if multiplexed HARQ-ACK payload size is one or two, gNB can receive any UL-SCH without blind detection under Alt 1 (and Alt 4?) since the multiplexing is performed in a puncture manner. That is, the real issue is only more than 2 bits case but no DL assignments, which would not be a typical situation. Of course this is not the case in type 1 HARQ-ACK CB, but FYI. |
| CATT | The benefit of Alt #1 is minimal or no specification impact. But as indicated above, we are also open to discuss Alt #2. Our understanding of Alt #2 is that T-DAI=0 for Type-1 HARQ-ACK CB and T-DAI=4 for Type-2 HARQ-ACK CB are used to indicate that there is no HARQ-ACK to be multiplexed on PUSCH. Therefore, there will be some scheduling restriction at gNB side. In this way, we do not think UE would multiplex HARQ-ACK in every PUSCH since it is expected that only one PUSCH is indicated to multiplex HARQ-ACK. Alt #3 is not quite clear to us. |
| Lenovo, Motorola Mobility | We prefer Alt#3 and we can live with Alt#1.  In Alt 1, T-DAI in UL grant should be followed; otherwise, the ambiguity between gNB and UE will be caused and the scheduled PUSCH can’t be correctly decoded.  In Alt 3, UE can select the latest scheduled PUSCH for multiplexing the HARQ-ACK information bits based on T-DAI in case there are multiple overlapping PUSCHs in the slot. |
| Huawei, HiSilicon | Our preference is Alt#3.  The issues for Alt#1 and Alt#2 are illustrated in Q1.  For Alt#3, the legacy prioritization rules can be reused. And the DAI field in the DCI can be used to identify the PUSCHs that are overlapped with the PUCCH. Therefore, the existing PUSCH prioritization rules can be reused as much as possible. |
| Intel | We share similar view as other companies that if we follow current specification, Alt. 1 is correct UE behavior as there is no overlapping PUCCH and PUSCH.  We prefer Alt. 1. |
| Samsung | Alt. 1 can be acceptable due to minimum specification impact. Since this is not general case since DCI missing event is rarely happened, optimization such as alt. 3 should be avoided in Rel-16. |
| Sharp | Specification should handle the issue. For the detailed solution, we should discuss Pros/Cons for each alternative. For Alt.2, we are negative with the same reason indicated by Qualcomm that multiplexing HARQ-ACK in all the PUSCH in the slot is inefficient. |
| Ericsson | We share the same view as Huawei |
| Apple | We prefer Alt.1 or Alt. 4. We don’t support Alt. 2, as it may lead to multiple UCI multiplexing in a slot. |
| Spreadtrum | Our preference is Alt 1. |

### Effect of CA vs non-CA operation

In RAN1 #105-e, there was a discussion on differentiating the CA and non-CA cases. However, multiple companies identified that (a) there is no differentiation between the two cases in the current specification with (b) some companies point out that they would prefer unified behavior in both cases. In [11], it was pointed out that two non-overlapping PUSCHs with a common overlapping PUCCH may have the same issue and as such, there should be a common solution for both.

#### Q3: Should we differentiate the solutions for the CA and non-CA cases ?

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| **Company** | **Comments** |
| ZTE | If possible, we of course support to define a unified solution for CA and non-CA cases. Otherwise, we think we should at least clarify and reach a same understanding about the most typical case (i.e., non-CA case) for Rel-16, with leaving to UE implementation for both cases for Rel-15 and CA case for Rel-16.  We would like to highlight that HARQ-ACK multiplexing on PUSCH in a single CC is a very typical case in real deployment. Leaving to UE implementation for such case would increase gNB complexity for blind decoding. |
| QC | No. We strongly object different solutions for CA vs non-CA. If RAN1 want to find a solution, let’s find a unified solution. We don’t see the motivation to introduce separate solutions for CA vs non-CA. |
| MTK | No. We do not see the necessity to introduce two different solutions here. |
| Nokia, NSB | Single uplink with more than 1 PUSCH in the same slot would have a similar problem, but it is not exactly the same problem as with the CA PUSCH selection as here the multiple PUSCH are always non-overlapping and never on different carriers, whereas in CA case the PUSCH are (obviously) on different carriers and at least typically time-overlapping. An unified solution that takes both the time and the frequency component into account could of course be envisioned. |
| Vivo | No. We do not see the necessity to introduce two different solutions. |
| NTT DOCOMO | No. Even in non-CA case, two TDMed PUSCH can be scheduled and one PUCCH can be overlapped with the two PUSCH. When the DL assignment is missed, the situation is the same as CA case. |
| CATT | No. A unified solution is desired. |
| Lenovo, Motorola Mobility | We think the problem happens in both CA case and non-CA case as long as there are multiple PUSCHs in same slot. So a unified solution is preferred from our side. |
| Huawei, HiSilicon | We prefer to use a unified solution for CA and non-CA case. |
| Intel | No. We also prefer a unified solution for non-CA and CA case. |
| Samsung | No. we don’t see any difference of them. |
| Sharp | We don’t see the motivation to handle them differently. |
| Ericsson | No. We prefer unified solution for Rel-16.  In fact, our view is that for non-CA case, for dynamic HARQ-ACK CB, when UL DAI=1, if the UE misses DL assignment, the UE should multiplex one NACK in PUSCH based on the spec (both Rel-15 and Rel-16). However, as we mentioned before, we have to find ways to manage the Rel-15 situation , since it is too late for any change. |
| Apple | No, we prefer a unified solution. Further optimization between single CC vs CA for R16 is not desirable at this stage. |
| Spreadtrum | Same solution for CA and non-CA. |

# 1st Round Summary

### Rel-15 UEs Behavior

#### Q1: . In the case of multiple overlapping PUSCHs with no overlapping PUCCH, what is the UE behavior in Rel-15?

A summary of the positions of different companies is as follows:

* Alt 1: MTK, Vivo (1st choice), CATT, Apple (1st choice), spreadtrum (1st choice) (5 companies, 5 1st choice companies)
* Alt 2: ZTE (1st choice) : (1 company, 1 1st choice company)
* Alt 3: ZTE (2nd choice), Nokia/NSB(1st choice): (2 companies, 1 1st choice company)
* Alt 4: Qualcomm, Nokia/NSB(2nd choice), Vivo (2nd choice), NTT DOCOMO, Lenovo/Motorola Mobility, Huawei/HiSilicon, Intel, Samsung, Sharp, Ericsson, Apple (2nd choice), Spreadtrum (2nd choice) (12 companies, 8 1st choice companies)

Given the company positions, we suggest that Alt. 4 be selected for Rel-15.

**Proposal 1:**

For Rel-15, in the case of multiple overlapping PUSCHs with no overlapping PUCCH, the UE behavior is left to UE implementation.

### Rel-16 UEs

#### Q2: . In the case of multiple overlapping PUSCHs with no overlapping PUCCH, what is the UE behavior in Rel-16?

A summary of the positions of different companies is as follows:

* Alt 1: MTK, Vivo, NTT DOCOMO (1st choice) CATT (1st choice), Lenovo (2nd choice), Intel, Samsung, Apple (1st choice), Spreadtrum (9 companies, 8 1st choice companies)
* Alt 2: ZTE (1st choice), CATT (2nd choice) : (2 companies, 1 1st choice company)
* Alt 3: ZTE (2nd choice), QC, Nokia/NSB, Lenovo (1st choice), Huawei, Ericsson (6 companies, 5 1st choice company)
* Alt 4: Apple (2nd choice), NTT DOCOMO (2nd choice) (2 companies, no 1st choice company)

Given the outcome of the discussion, we suggest that **we down-select to Alt-1 and Alt-3**.

For Alt-3, we also need to clarify the specific method by which the PUSCH to be multiplexed on is selected. As at now, we have the following methods proposed:

* *Alt 3-1: define a default/reference PUCCH resource, and use that default/reference PUCCH to start the UCI multiplexing procedure.*
* *Alt 3-2: 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:* 
  + *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*
* *Alt 3-4: Any other method*

For Alt 3-1, we would need to **clarify what the default PUCCH reference would be**. For Alt 3-3, we will need to **clarify the current PUSCH prioritization rules**. Some of these rules are captured in Section 5.3 in the Appendix but it would be good to verify that there are the rules being proposed.

### Effect of CA vs non-CA operation

#### Q3: Should we differentiate the solutions for the CA and non-CA cases ?

A summary of the positions of different companies is as follows:

* No: Qualcomm, MediaTek, Nokia/NSB, Vivo, NTT DOCOMO,CATT, Lenovo/Motorola Mobility, Huawei/Hisilicon, Intel, Samsung, Sharp, Ericsson, Apple, ZTE (if possible) (13 companies)
* Clarify behavior: ZTE (1)

Based on the outcome, there seems to be a consensus that we should have the same solutions for both.

Conclusion:

We can consider both during the discussion but RAN1 should find a unified solution.

# 2nd Round

### **Proposal #1:**

*For Rel-15, in the case of multiple overlapping PUSCHs with no overlapping PUCCH, the UE behavior is left to UE implementation.*

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| **Company** | **Comments** |
| QC | We just noticed the proposal only covers multiple PUSCHs, should not the proposal cover a single PUSCH as well?  Another comment: The conditioning of the UL DAI value, “if UL-TDAI n.e. 4 (for Type 2 codebook) or UL-TDAI e.q. 1 (for Type 1 codebook)”, is missed in the proposal. I think for UL-TDAI = 4 (for Type 2 codebook) or UL-TDAI = 0 (for Type 1 codebook), spec is clear (UE does not multiplex) and it is not an error case. |
| CATT | Regarding Qualcomm’s 1st comment, our understanding of the issue is that if there are multiple PUSCHs, UE do not know which PUSCH to select for multiplexing. For single PUSCH, there should be no problem unless we take UL DCI miss into account. So is the intention to consider this case?  We support Qualcomm’s 2nd comment.  In addition, we would like to clarify that the PUCCH include PUCCH for SPS HARQ-ACK. |
| MTK | We still prefer Alt. 1, but we can be ok for Alt. 4 (current moderator proposal) if we are the only company objecting this. |
| Sharp | We are OK with the proposal. |
| Lenovo, Motorola Mobility | Generally fine with us.  Rewording may be needed to address UL DAI=1 or 4 case as mentioned by Qualcomm. |
| Nokia, NSB | We are OK with the proposal in principle, but agree that Qualcomm’s “Another comment” should be taken in the proposal.  @QC: What is the issue with single PUSCH?  @MTK: Alt1 formulation was inaccurate as it asserted that the HARQ-ACK is not sent because there was no overlapping PUCCH, when the lack of overlapping PUCCH is not of an issue, the selection of the PUSCH is. |

### **Proposal #2:**

*For Rel-16, focus on Alt #1 and Alt #3 where:*

* **Alt #1**: the UE does not multiplex HARQ-ACK information in any PUSCH since there is no overlapping PUCCH and PUSCH.
* **Alt #3:** 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.

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| **Company** | **Comments** |
| QC | We are fine with the proposal. But it seems the proposal is not complete – meaning the “ in case of …” is missing in the sentence above the two bullets. |
| CATT | Between Alt #1 and 3, we support Alt #1 and we do not agree with Alt #3. It is clear that Alt #3 is not maintenance but a new feature. It is not within the scope of the discussion. In addition, if proposal #1 is acceptable for Rel-15, why is a new feature needed for Rel-16? |
| MTK | Our preference is Alt .1, but we can accept this proposal to narrow down candidates for progress. |
| Sharp | We are OK with the proposal. |
| Lenovo, Motorola Mobility | We prefer Alt#3 and we can live with Alt#1.  In Alt 1, T-DAI in UL grant should be followed; otherwise, the ambiguity between gNB and UE will be caused and the scheduled PUSCH can’t be correctly decoded.  In Alt 3, UE can select the latest scheduled PUSCH for multiplexing the HARQ-ACK information bits based on T-DAI in case there are multiple overlapping PUSCHs in the slot. |
| Nokia, NSB | In principle OK to focus on Alt1 and Alt 3, but:  **Not OK with Alt1 formulation**, as it implies that the issue is that there is no overlapping PUCCH, when that is not the issue, the PUSCH selection is the issue. |

### **Proposal #3:**

*For Alt-3, the PUSCH to be multiplexed on is selected by:*

* *Alt 3-1: define a default/reference PUCCH resource, and use that default/reference PUCCH to start the UCI multiplexing procedure.* 
  + *Please give specifics on how the specific PUCCH resource is defined.*
* *Alt 3-2: 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:* 
  + *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*
  + *Please detail the current PUSCH prioritization rules e.g. by agreements or specification reference*
  + *NOTE: There are no PUSCH prioritization rules specified in Rel 15 without an overlapping PUCCH (See Appendix* 5.3)
* *Alt 3-4: Any other method*

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| **Company** | **Comments** |
| QC | We support this proposal. For Alt 3-1, to keep it simple, the reference PUCCH can be a PUCCH of 14 OFDM symbols cross the slot.  We are also interested to see how the one PUSCH is selected with Alt 3-3. |
| CATT | As commented above, we do not agree with Alt-3. |
| MTK | We are open for further discussion in this proposal although we prefer Alt.1. |
| Sharp | We are OK with the proposal. |
| Lenovo, Motorola Mobility | We prefer Alt 3-2. |
| Nokia, NSB | We are OK with the proposal |

### Question 1:

***To enable an understanding of the different choices, companies should detail pros and Cons of Alt-1 and Alt-3****:*

|  |  |  |
| --- | --- | --- |
| **Company** | **Comments** | |
| QC | **Alt 1 Pros** |  |
| **Alt 1 Cons** | This is against the purpose to introduce UL DAI. gNB need to do blind detection for PUSCH decoding. |
| **Alt 3-1 Pros** | With a reference PUCCH, the Rel-15 multiplexing procedure can be reused. It is unified UCI multiplexing behavior between nominal case (where PUCCH exist) and this special case (where PUCCH is absent). To keep it simple, the reference PUCCH can be a PUCCH of 14 OFDM symbols cross the slot. |
| **Alt 3-1 Cons** |  |
| **Alt 3-2 Pros** | Always multiplexing on the last received UL grant allow gNB make “last minute” change of scheduling decision. It also simplified UE multiplexing procedure. |
| **Alt 3-2 Cons** |  |
| **Alt 3-3 Pros** |  |
| **Alt 3-3 Cons** |  |
| MTK | The pros of Alt. 1 is minimal (or even zero) spec impact.  The pros of Alt. 3 is an enhancement for UL DAI usage.  For Rel-16, to change spec to apply Alt. 3, we would expect some simulation or analytical results to demonstrate the achievable gain (should be evident enough to apply a R16 spec change for enhancement) from the proponents of Alt. 3, since to our understanding DCI missing event is rarely happened (as also mentioned by Samsung).  Hence, currently we prefer Alt. 1 for Rel-16. | |
| Sharp | **Alt 1 Pros** |  |
| **Alt 1 Cons** | Blind decoding by gNB side is required even when expected HARQ-ACK bits are 1 or 2 if P-CSI also overlaps with the PUSCHs. |
| **Alt 3-1 Pros** |  |
| **Alt 3-1 Cons** | It is not clear how to perform UCI multiplexing for multiple PUCCH when a reference resource defined for it overlaps with P-CSI. In that case, new PUCCH resource is determined based on 0+Y bits where the reference resource assumes 0 bit UCI and P-CSI is Y bits? |
| **Alt 3-2 Pros** | No issue found so far. |
| **Alt 3-2 Cons** |  |
| **Alt 3-3 Pros** | No issue found so far. |
| **Alt 3-3 Cons** |  |
| Lenovo, Motorola Mobility | For Alt 1, T-DAI in UL grant does not be followed so that the ambiguity between gNB and UE will be caused.  For Alt 3, a predefined rule is needed for the UE to select one PUSCH. Always following the latest UL DAI seems simple and gives gNB scheduling flexibility. | |
| Nokia, NSB | **Alt1:** Behaviour is not what it is supposed to be – there should be HARQ-ACK in one of the PUSCH  **Alt3-1:** We see this as a workable and potentially simple approach.  **@Sharp**: If there is P-CSI then wouldn’t there be a PUCCH resource for that P-CSI as well and the reference resource would be meaningless?  **Alt3-2:** No issue found so far  **Alt3-3**: No issue found so far, but on the face of it appears a bit more complex | |

# References

1. R1-2105079, “Discussions on PUSCH UCI Multiplexing without HARQ-ACK PUCCH in Rel-15,” Apple Inc., RAN1 #105-e.
2. R1-2105390, “Clarification on HARQ-ACK Information Feedback without Receiving DL assignment/PDSCH”, MediaTek Inc., RAN1 #105-e
3. 3GPP TS 38.213, v15.13.0.
4. Chairman’s Notes, RAN1 #97
5. R1-1907441, Multiplexing of overlapping PUCCH and PUSCH with different numerologies, Nokia, RAN1 #97
6. R1-2106327, Summary for [105-e-NR-7.1CRs-02] Discussions on PUSCH UCI Multiplexing without HARQ-ACK PUCCH, Moderator (Apple)
7. R1-2107310 Discussion on HARQ-ACK multiplexing on PUSCH without PUCCH Qualcomm Incorporated
8. R1-2107506 Clarification on Multiplexing HARQ-ACK Information in PUSCH without PUCCH MediaTek Inc.
9. R1-2107672 Discussion on the UCI multiplexing Huawei, HiSilicon
10. R1-2107711 Discussions on PUSCH UCI Multiplexing without HARQ-ACK PUCCH in Rel-15 and Rel-16 Apple
11. R1-2107835 Discussion on HARQ-ACK multiplexing on PUSCH without PUCCH overlapping NTT DOCOMO, INC.

# Appendix: Background

### Type 1 HARQ ACK Codebook [2]

In Section 9.1.2.2 of [3], 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 [1]

In Section 9.1.3.2 of [3], 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 [4][5]:

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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 [3] and the PUSCH prioritization rule for UCI multiplexing on PUSCH is specified in Section 9 of [3]:

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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

### Qualcomm: R1- 2017310 [7]

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| ***Proposal 1: Without updating Rel-15 specification, leave it up to UE implementation to handle the case of HARQ-ACK multiplexing on a group of PUSCHs without HARQ-ACK PUCCH. RAN1 aim to find a solution for this case in Rel-16 specification.***  ***Proposal 2: In Rel-16 specification, solve the issue of HARQ-ACK multiplexing on a group of PUSCHs without HARQ-ACK PUCCH by taking one of the following options.***   * ***Option 1: define a default/reference PUCCH resource, and use that default/reference PUCCH to start the UCI multiplexing procedure.*** * ***Option 2: 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.*** |

### MediaTek : R1-2107506 [8]

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| Based on the discussion in Section 2, we have the following proposals.  **Proposal 1: For both Rel-15 and Rel-16, when the value of DAI field in DCI format 0\_1 is for Type 1 HARQ-ACK codebook in PUSCH (or for Type 2 HARQ-ACK codebook in PUSCH), the UE does not multiplex HARQ-ACK information in any PUSCH if there is no overlapping PUCCH and PUSCH.**  **Proposal 2: Support unified UE behaviour for both CA and non-CA cases.** |

### Huawei: R1-2107672 [9]

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| ***Proposal 1: A UE multiplexes HARQ-ACK in PUSCH if the UE does not receive PDSCH/PDCCH that needs HARQ-ACK feedback following the indication of UL DAI filed in DCI.***   * ***For type-1 HARQ codebook, the DAI field is equal to 1*** * ***For type-2 HARQ codebook, the DAI filed is equal to 1/2/3***   ***Observation: A UE cannot distinguish whether there is one single overlapping PUSCHs group or not according to UL DCI with DAI field value equaling to 1 under the multiple DL DCI missing case, mixed numerology case, URLLC case.***  ***Proposal 2: 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***   ***Proposal 3: Same rules of multiple overlapping PUSCHs UCI multiplexing without PUCCH should be reused for multiple overlapping PUSCHs UCI multiplexing with PUCCH for both type-1 HARQ-ACK codebook and type-2 HARQ-ACK codebook.*** |

### Apple : R1-2107711 [10]

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| ***Proposal 1:***   * *For Rel-15 UEs, i****n the case of multiple overlapping PUSCHs with no overlapping PUCCH,*** *the UE behavior is left to UE implementation.*   ***Proposal 2:***   * *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.* |

### NTT DOCOMO: R1-2107835 [11]

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| **Observation 1:**   * *Current specifications do not define UE behavior in the situation illustrated in Fig.1.*   **Proposal 1:**   * *In Rel-15, UE behavior in the situation illustrated in Fig.1 is not defined.*   **Observation 2:**   * *When HARQ-ACK payload size multiplexed on a PUSCH is 1 or 2 bits, the multiplexing is performed in a puncture manner. In this case, gNB can detect UL-SCH and/or CSI without blind detection in the situation illustrated in Fig.1.* * *For Type 2 HARQ-ACK CB, multiplexing more than 2 bits HARQ-ACK on a PUSCH in the situation illustrated in Fig.1 would be a corner case.* * *For Type 1 HARQ-ACK CB, multiplexing more than 2 bits HARQ-ACK on a PUSCH in the situation illustrated in Fig.1 would be a typical case.*   **Proposal 2:**   * *In Rel-16,*   + *For Type 2 HARQ-ACK CB, UE does not multiplex HARQ-ACK on a PUSCH if the UE does not have a PUCCH transmission that is including HARQ-ACK and is overlapped with the PUSCH even when UL DAI corresponding to the PUSCH indicates HARQ-ACK multiplexing.*   + *For Type 1 HARQ-ACK CB, FFS.*   **Observation 3:**   * *It seems that separate discussion between CA case and non-CA case is not valid.* |