**3GPP TSG-RAN WG1 Meeting #104bis-eR1-210xxxx**

**e-Meeting, April 12th – April 20th, 2021**

**Agenda item:** **7.1**

**Source: Moderator (Apple Inc.)**

**Title: Summary of email discussion [104b-e-NR-7.1CRs-04] on the correction for HARQ-ACK timing**

**Document for: Discussion and Decision**

# 1 Introduction

This contribution provides the summary for the following email discussion in RAN1#104bis-e:

[104b-e-NR-7.1CRs-04] Issue#24: Correction for HARQ-ACK timing in Rel-15 and Rel-16 – Sigen (Apple) by April 16

R1-2103077 Correction for HARQ-ACK timing in Rel-15 and Rel-16 Apple, Ericsson

Section 2 provides the background information for the issues raised in [1]. Section 3 captures the detailed email discussions. Section 4 summarizes the outcome of the email discussion.

# 2 Background

In [1], the issue regarding how to determine the HARQ-ACK timing for the case when DL and UL have different numerologies was raised. The following background information is copied from [1].

For HARQ-ACK, the PUCCH for HARQ-ACK is transmitted in UL slot *n+k*, where *k* is indicated in UL DCI, and *n* is determined based on PDSCH. When DL and UL have different numerology, the understanding in [1] is that slot *n* is determined based on the end of the slot for PDSCH. However, the specification seems to imply that slot *n* is determined based on the end of PDSCH. The HARQ-ACK timing is specified as follows in TS 38.213.

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| 9.2.3 UE procedure for reporting HARQ-ACKA UE does not expect to transmit more than one PUCCH with HARQ-ACK information in a slot. For DCI format 1\_0, the PDSCH-to-HARQ\_feedback timing indicator field values map to {1, 2, 3, 4, 5, 6, 7, 8}. For DCI format 1\_1, if present, the PDSCH-to-HARQ\_feedback timing indicator field values map to values for a set of number of slots provided by *dl-DataToUL-ACK* as defined in Table 9.2.3-1. For a SPS PDSCH reception ending in slot , the UE transmits the PUCCH in slot where  is provided by the PDSCH-to-HARQ\_feedback timing indicator field in DCI format 1\_0 or, if present, in DCI format 1\_1 activating the SPS PDSCH reception. If the UE detects a DCI format 1\_1 that does not include a PDSCH-to-HARQ\_feedback timing indicator field and schedules a PDSCH reception or activates a SPS PDSCH reception ending in slot , the UE provides corresponding HARQ-ACK information in a PUCCH transmission within slot  where  is provided by *dl-DataToUL-ACK*.With reference to slots for PUCCH transmissions, if the UE detects a DCI format 1\_0 or a DCI format 1\_1 scheduling a PDSCH reception ending in slot  or if the UE detects a DCI format 1\_0 indicating a SPS PDSCH release through a PDCCH reception ending in slot , the UE provides corresponding HARQ-ACK information in a PUCCH transmission within slot , where  is a number of slots and is indicated by the PDSCH-to-HARQ\_feedback timing indicator field in the DCI format, if present, or provided by *dl-DataToUL-ACK*.  corresponds to the last slot of the PUCCH transmission that overlaps with the PDSCH reception or with the PDCCH reception in case of SPS PDSCH release.  |

Following the highlighted text, for the case with different numerologies between DL and UL, for the example in Fig. 1, *k*=0 would correspond to UL slot 6.



**Figure 1 Example of HARQ-ACK timing**

However, we had the following agreement in RAN1#93, which suggests that for the example in Fig. 1, *k*=0 should correspond to UL slot 7.

Agreements**:**

* When HARQ-ACK for the PDSCH with larger SCS is transmitted on a carrier with smaller SCS
	+ K1=0 corresponds to the slot for the smaller SCS which overlaps with the PDSCH
* When HARQ-ACK for the PDSCH with smaller SCS is transmitted on a carrier with larger SCS
	+ K1=0 corresponds to the slot for the larger SCS with end boundary aligned to the slot for the corresponding PDSCH

The above agreements were captured in TS 38.213 v15.2.0 as follows:



However, in RAN1#95, an issue was raised in [R1-1813531](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_95/Docs/R1-1813531.zip) for the highlighted text because it could not cover the case when one carrier uses NCP and another carrier uses ECP, where the slot boundary may not be aligned between the two carriers. To resolve this issue, the following was agreed in CR [R1-1814332](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_95/Docs/R1-1814332.zip) (as shown below), which is also reflected in the latest version of the specification.

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| 9.2.3 UE procedure for reporting HARQ-ACK< Unchanged parts are omitted >With reference to slots for PUCCH transmissions, if the UE detects a DCI format 1\_0 or a DCI format 1\_1 scheduling a PDSCH reception ending in slot  or if the UE detects a DCI format 1\_0 indicating a SPS PDSCH release through a PDCCH reception ending in slot , the UE provides corresponding HARQ-ACK information in a PUCCH transmission within slot , where  is a number of slots and is indicated by the PDSCH-to-HARQ-timing-indicator field in the DCI format, if present, or provided by *dl-DataToUL-ACK*. If the PDSCH SCS is equal to or larger than the PUCCH SCS or, in case of SPS PDSCH release if the PDCCH SCS is equal to or larger than the PUCCH SCS,  corresponds to the last slot of the PUCCH transmission that overlaps with the PDSCH reception or of the PDCCH reception in case of SPS PDSCH release. If the PDSCH SCS is smaller than the PUCCH SCS or, in case of SPS PDSCH release if the PDCCH SCS is smaller than the PUCCH SCS,  corresponds to the last slot of the PUCCH transmission that overlaps withthe PDSCH reception or of the PDCCH reception in case of SPS PDSCH release. < Unchanged parts are omitted > |

The description in the specification that had caused issues in case of mis-aligned slot boundaries, was the constraint that UL slot and DL slot including PDSCH “end at the same time”. However, when the corresponding CR resolved the issue and removed the constraint by usage of “last” overlapping UL slot, it *unnecessarily* removed “the slot” of PDSCH as well. This resulted with the new text that actually deviates from the original intention of using the end of the DL slot for the PDSCH as the reference to determine UL slot *n* (or *k* = 0). As explained earlier, for the example in Fig. 1, the current text means that *k* = 0 corresponds to UL slot 6, but according to the agreements, *k* = 0 should correspond to UL slot 7.

Another reason that the end of DL slot instead of the end of PDSCH should be used is that the Type-1 HARQ-ACK codebook construction already assumes the end of DL slot. Basically, the highlighted part below only makes sense if the end of DL slot is used as the reference.

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| **Excerpt from TS 38.213 Clause 9.1.2.1**Graphical user interface, text, application  Description automatically generated |

In addition, similar issues exist for the following:

* In TS 38.213 Clause 9.2.3, the definition of k=0 should apply to all cases, including HARQ-ACK for SPS PDSCH and PDSCH scheduled by a DCI format 1\_1 that does not include a PDSCH-to-HARQ\_feedback timing indicator field (two previous paragraphs in Clause 9.2.3).
* A Rel-16 CR was agreed in [R1-2101927](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_104-e/Docs/R1-2101927.zip) (RAN1#104-e) for the HARQ-ACK timing for PDSCH with repetitions to properly handle different numerologies between DL and UL. The wording also implies that the end of the PDSCH instead of the end of the corresponding DL slot is considered.

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| 9.1.2 Type-1 HARQ-ACK codebook determinationThis Clause applies if the UE is configured with *pdsch-HARQ-ACK-Codebook = semi-static*.A UE reports HARQ-ACK information for a corresponding PDSCH reception or SPS PDSCH release only in a HARQ-ACK codebook that the UE transmits in a slot indicated by a value of a PDSCH-to-HARQ\_feedback timing indicator field in a corresponding DCI format. The UE reports NACK value(s) for HARQ-ACK information bit(s) in a HARQ-ACK codebook that the UE transmits in a slot not indicated by a value of a PDSCH-to-HARQ\_feedback timing indicator field in a corresponding DCI format. If a UE is not provided *pdsch-HARQ-ACK-OneShotFeedback*, the UE does not expect to receive a PDSCH scheduled by a DCI format that the UE detects in any PDCCH monitoring occasion and includes a PDSCH-to-HARQ\_feedback timing indicator field providing an inapplicable value from *dl-DataToUL-ACK-r16*.If the UE is provided *pdsch-AggregationFactor-r16* in *SPS-Config* or *pdsch-AggregationFactor* in *PDSCH-Config* and no entry in *pdsch-TimeDomainAllocationList* and *pdsch-TimeDomainAllocationListDCI-1-2* includes *repetitionNumber* in *PDSCH-TimeDomainResourceAllocation-r16*, $N\_{PDSCH}^{repeat,max}$ is a maximum value of *pdsch-AggregationFactor-r16* in *SPS-Config* or *pdsch-AggregationFactor* in *PDSCH-Config*; otherwise $N\_{PDSCH}^{repeat,max}=1$. The UE reports HARQ-ACK information for a PDSCH reception- from DL slot $\_{}^{}n\_{D}-N\_{PDSCH}^{repeat}+1$ to DL slot $n\_{D}$, if $N\_{PDSCH}^{repeat}$ is provided by *pdsch-AggregationFactor* or *pdsch-AggregationFactor-r16* [6, TS 38.214], or - from DL slot $ n\_{D}-repetitionNumber+1$ to DL slot $n\_{D}$, if the time domain resource assignment field in the DCI format scheduling the PDSCH reception indicates an entry containing *repetitionNumber,* or - in DL slot $n\_{D}$, otherwise only in a HARQ-ACK codebook that the UE includes in a PUCCH or PUSCH transmission in slot $n+k$, where $n$ is a UL slot overlapping with the end of the PDSCH reception in DL slot $n\_{D}$ and $k$ is a number of slots indicated by the PDSCH-to-HARQ\_feedback timing indicator field in a corresponding DCI format or provided by *dl-DataToUL-ACK* if the PDSCH-to-HARQ\_feedback timing indicator field is not present in the DCI format. If the UE reports HARQ-ACK information for the PDSCH reception in a slot other than slot $n+k$, the UE sets a value for each corresponding HARQ-ACK information bit to NACK.  |

Following the discussions, the following TPs were proposed in [1] for Rel-15 and Rel-16.

## **Proposal 1:**

**Adopt the following TP for TS 38.213 for Rel-15:**

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| **TP for TS 38.213 Clause 9.2.3**9.2.3 UE procedure for reporting HARQ-ACKA UE does not expect to transmit more than one PUCCH with HARQ-ACK information in a slot. For DCI format 1\_0, the PDSCH-to-HARQ\_feedback timing indicator field values map to {1, 2, 3, 4, 5, 6, 7, 8}. For DCI format 1\_1, if present, the PDSCH-to-HARQ\_feedback timing indicator field values map to values for a set of number of slots provided by *dl-DataToUL-ACK* as defined in Table 9.2.3-1. For a SPS PDSCH reception ending in slot , the UE transmits the PUCCH in slot where  is provided by the PDSCH-to-HARQ\_feedback timing indicator field in DCI format 1\_0 or, if present, in DCI format 1\_1 activating the SPS PDSCH reception. If the UE detects a DCI format 1\_1 that does not include a PDSCH-to-HARQ\_feedback timing indicator field and schedules a PDSCH reception or activates a SPS PDSCH reception ending in slot , the UE provides corresponding HARQ-ACK information in a PUCCH transmission within slot  where  is provided by *dl-DataToUL-ACK*.With reference to slots for PUCCH transmissions, if the UE detects a DCI format 1\_0 or a DCI format 1\_1 scheduling a PDSCH reception ending in slot  or if the UE detects a DCI format 1\_0 indicating a SPS PDSCH release through a PDCCH reception ending in slot , the UE provides corresponding HARQ-ACK information in a PUCCH transmission within slot , where  is a number of slots and is indicated by the PDSCH-to-HARQ\_feedback timing indicator field in the DCI format, if present, or provided by *dl-DataToUL-ACK*.  corresponds to the last UL slot that overlaps with the DL slot for the PDSCH reception or the PDCCH reception in case of SPS PDSCH release. < Unchanged parts are omitted > |

Here is the TP for TS 38.213 Rel-16. Note that this TP also corrects a typo in the HARQ-ACK timing for PDSCH with repetitions.

## **Proposal 2:**

**Adopt the following TP for TS 38.213 for Rel-16:**

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| **TP for TS 38.213**9.1.2 Type-1 HARQ-ACK codebook determinationThis Clause applies if the UE is configured with *pdsch-HARQ-ACK-Codebook = semi-static*.A UE reports HARQ-ACK information for a corresponding PDSCH reception or SPS PDSCH release only in a HARQ-ACK codebook that the UE transmits in a slot indicated by a value of a PDSCH-to-HARQ\_feedback timing indicator field in a corresponding DCI format. The UE reports NACK value(s) for HARQ-ACK information bit(s) in a HARQ-ACK codebook that the UE transmits in a slot not indicated by a value of a PDSCH-to-HARQ\_feedback timing indicator field in a corresponding DCI format. If a UE is not provided *pdsch-HARQ-ACK-OneShotFeedback*, the UE does not expect to receive a PDSCH scheduled by a DCI format that the UE detects in any PDCCH monitoring occasion and includes a PDSCH-to-HARQ\_feedback timing indicator field providing an inapplicable value from *dl-DataToUL-ACK-r16*.If the UE is provided *pdsch-AggregationFactor-r16* in *SPS-Config* or *pdsch-AggregationFactor* in *PDSCH-Config* and no entry in *pdsch-TimeDomainAllocationList* and *pdsch-TimeDomainAllocationListDCI-1-2* includes *repetitionNumber* in *PDSCH-TimeDomainResourceAllocation-r16*, $N\_{PDSCH}^{repeat,max}$ is a maximum value of *pdsch-AggregationFactor-r16* in *SPS-Config* or *pdsch-AggregationFactor* in *PDSCH-Config*; otherwise $N\_{PDSCH}^{repeat,max}=1$. The UE reports HARQ-ACK information for a PDSCH reception- from DL slot $n\_{D}-N\_{PDSCH}^{repeat}+1$ to DL slot $n\_{D}$, if $N\_{PDSCH}^{repeat}$ is provided by *pdsch-AggregationFactor* or *pdsch-AggregationFactor-r16* [6, TS 38.214], or - from DL slot $ n\_{D}-repetitionNumber+1$ to DL slot $n\_{D}$, if the time domain resource assignment field in the DCI format scheduling the PDSCH reception indicates an entry containing *repetitionNumber,* or - in DL slot $n\_{D}$, otherwise only in a HARQ-ACK codebook that the UE includes in a PUCCH or PUSCH transmission in slot $n+k$, where $n$ is the last UL slot overlapping with DL slot $n\_{D}$ and $k$ is a number of slots indicated by the PDSCH-to-HARQ\_feedback timing indicator field in a corresponding DCI format or provided by *dl-DataToUL-ACK* if the PDSCH-to-HARQ\_feedback timing indicator field is not present in the DCI format. If the UE reports HARQ-ACK information for the PDSCH reception in a slot other than slot $n+k$, the UE sets a value for each corresponding HARQ-ACK information bit to NACK. < Unchanged parts are omitted >9.2.3 UE procedure for reporting HARQ-ACKA UE does not expect to transmit more than one PUCCH with HARQ-ACK information in a slot per priority index, if the UE is not provided *ackNackFeedbackMode = separate*. For DCI format 1\_0, the PDSCH-to-HARQ\_feedback timing indicator field values map to {1, 2, 3, 4, 5, 6, 7, 8}. For a DCI format, other than DCI format 1\_0, scheduling a PDSCH reception or a SPS PDSCH release, the PDSCH-to-HARQ\_feedback timing indicator field values, if present, map to values for a set of number of slots provided by *dl-DataToUL-ACK*, *dl-DataToUL-ACK-r16*, or *dl-DataToUL-ACKForDCIFormat1\_2*, as defined in Table 9.2.3-1. For a SPS PDSCH reception ending in slot , the UE transmits the PUCCH in slot $n+k$ where $k$ is provided by the PDSCH-to-HARQ\_feedback timing indicator field, if present, in a DCI format activating the SPS PDSCH reception. If the UE detects a DCI format that does not include a PDSCH-to-HARQ\_feedback timing indicator field and schedules a PDSCH reception or activates a SPS PDSCH reception ending in slot $n$, the UE provides corresponding HARQ-ACK information in a PUCCH transmission within slot $n+k$ where $k$ is provided by *dl-DataToUL-ACK*, or *dl-DataToUL-ACK-r16*, or *dl-DataToUL-ACKForDCIFormat1\_2*.With reference to slots for PUCCH transmissions, if the UE detects a DCI format scheduling a PDSCH reception ending in slot $n$ or if the UE detects a DCI format indicating a SPS PDSCH release or indicating SCell dormancy through a PDCCH reception ending in slot $n$, or if the UE detects a DCI format that requests Type-3 HARQ-ACK codebook report and does not schedule a PDSCH reception through a PDCCH reception ending in slot $n$, as described in Clause 9.1.4, the UE provides corresponding HARQ-ACK information in a PUCCH transmission within slot $n+k$, where $k$ is a number of slots and is indicated by the PDSCH-to-HARQ\_feedback timing indicator field in the DCI format, if present, or provided by *dl-DataToUL-ACK*, *dl-DataToUL-ACK-r16*, or *dl-DataToUL-ACKForDCIFormat1\_2*. $k=0$ corresponds to the last UL slot that overlaps with the DL slot for the PDSCH reception or the PDCCH reception in case of SPS PDSCH release or in case of SCell dormancy indication or in case of the DCI format that requests Type-3 HARQ-ACK codebook report and does not schedule a PDSCH reception. < Unchanged parts are omitted > |

# 3 Email Discussions

## 3.1 First Round of Email Discussion

For HARQ-ACK timing in case DL and UL have different numerologies, there are two different interpretations:

* Interpretation 1: *k* = 0 corresponds to the last UL slot that overlaps with the PDSCH
* Interpretation 2: *k* = 0 corresponds to the last UL slot that overlaps with the DL slot for the PDSCH

Interpretation 1 seems to be implied by the latest version of the specification. Interpretation 2 is supported by previous RAN1 agreements and the older version of the specification, and it is also aligned with the pseudo-code for Type-1 HARQ-ACK codebook construction.

For the following example, interpretation 1 means that k = 0 corresponds to UL slot 6, while interpretation 2 means that k = 0 corresponds to UL slot 7.



**Companies please indicate which one is your understanding.**

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| **Interpretation 1** | CATT, WILUS, vivo, Samsung |
| **Interpretation 2** | Qualcomm, Huawei, HiSilicon |

**Companies please provide detailed comments.**

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| **Company** | **Comments** |
| CATT | As commented during preparation phase, the same issue was discussed in R1-1902867 and R1-1901978 in RAN1#96. The issue was well understood at that time as discussed in the respective discussion papers. The CR in R1-1902867 was rejected. We see no reason to re-open the discussion two years later.[**R1-1902867**](file:///D%3A%5CDocuments%5CWork%5CStds%5CRAN1%5CRAN1_96_Athens%5CR1-1902867.zip) Draft CR on reference slot for PUCCH transmission with HARQ-ACK WILUS Inc.Discuss further offlineNote: the above draft CR may affect at least operation with normal CP in DL/UL and extended CP in UL/DL |
| WILUS | As we pointed out during preparation phase, the interpretation 2 was rejected in RAN1#96 meeting so that it is clear that the interpretation 1 was common understanding for Rel-15 specification. Even for Rel-16, the proposed change (interpretation#2) still does not address type-1 HARQ-ACK CB construction issue at least in the following NCP/ECP cases. For example, consider the case where PDSCHs are scheduled in 60kHz NCP cell and PUCCH is transmitted in 60kHz ECP cell. Assume the PUCCH carrying type-1 HARQ-ACK CB is transmitted in slot *n*+2 and K1=1 is configured. According to the proposed change, the type-1 HARQ-ACK CB should include HARQ-ACK information for PDSCH#1 and PDSCH#2 since two PDSCH (#1 and #2) can be scheduled with K1=1. However, the type-1 HARQ-ACK CB only include PDSCH#2 in Rel-16 specification (it is because $μ\_{DL}= μ\_{UL}$ in “while ” of the pseudo-code). |
| vivo | Technically, we share the views that the interpretation 2 is aligned with the agreements. But as other companies pointed out the same issue was already discussed without any correction. Hence, we share CATT’s views that seems no good reason to re-open the discussion.  |
| Samsung | As mentioned by CATT and other companies, a similar CR was proposed in RAN1#96 and rejected. Therefore, there is no good reason to re-open the discussion. |
| Spreadtrum | Share same view as CATT. It does not need to discussion this issue again.  |
| Qualcomm | The slot of the PDSCH reception is the reference for k=0, rather than the actual PDSCH symbols. The discussion paper R1-2103077 explains various reasons why the changes are necessary. Very specific case (NCP + ECP) should not be the limiting factor to resolve the issue of very typical scenario. |
| Huawei, HiSilicon | We understand this issue was discussed before and R1-1902867 was rejected for some reason. We also acknowledge that the proposed change may not work for some ECP case. However, it is crucial to have common understanding on the other cases.  |
| ZTE | Share same view as CATT. No need to discuss. |

For the companies supporting interpretation 2, please indicate if you support the Rel-15 TP in Proposal 1 and provide comments if any.

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| **Company** | **Comments** |
| Qualcomm | We are OK with having Rel-15 CR to clarify the intention.Regarding the proposed TP, we have a couple of comments:* On the TP for Section 9.2.3, “the last UL slot ~~of the PUCCH transmission~~” seems excluding flexible or special slot that can accommodate PUCCH transmission, which would not be the intention.
* Similarly, “the DL slot for the PDSCH reception” has the same issue.

Therefore, it would be better not to use “UL” or “DL”, for example:* *k*=0 corresponds to the last slot for ~~of the~~ PUCCH transmission that overlaps with the ~~DL~~ slot for the PDSCH reception or ~~with~~ the PDCCH reception in case of SPS PDSCH release.
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| Huawei, HiSilicon | We are fine with the proposed change from QC.  |
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For the companies supporting interpretation 2, please indicate if you support the Rel-16 TP in Proposal 2 and provide comments if any.

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| **Company** | **Comments** |
| Qualcomm | We support to have the Rel-16 CR.Regarding the proposed TP for Section 9.2.3, same comments as for Rel.15 TP above.Regarding the proposed TP for Section 9.1.2, similar change would be preferred, for example:* only in a HARQ-ACK codebook that the UE includes in a PUCCH or PUSCH transmission in slot *n*+*k*, where *n* is ~~a~~ the last ~~UL~~ slot for PUCCH transmission overlapping with ~~the end of the PDSCH reception in~~ DL slot *nD* and *k* is a number of slots indicated by the PDSCH-to-HARQ\_feedback timing indicator field in a corresponding DCI format …
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| Huawei, HiSilicon | We are fine with the proposed change from QC. |
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## 3.2 Second Round of Email Discussion

# 4 Outcome of the Email Discussion

# References

1. R1-2103077 Correction for HARQ-ACK timing in Rel-15 and Rel-16 Apple, Ericsson