**3GPP TSG-RAN WG1 Meeting #106-eR1-210xxxx**

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

**Agenda item:** **7.2.5**

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

**Title: Summary of email discussion [106-e-NR-L1enh-URLLC-03] on sub-slot-based HARQ-ACK timing in Rel-16**

**Document for: Discussion and Decision**

# 1 Introduction

This contribution provides the summary for the following email discussion in RAN1#106-e:

* [106-e-NR-L1enh-URLLC-03] Issue#7: HARQ-ACK timing for sub-slot based HARQ-ACK feedback by August 20 – Sigen (Apple)

Section 2 provides the background information. Section 3 captures the detailed email discussions. Section 4 summarizes the outcome of the email discussion.

# 2 Background

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 UL SCS is larger than DL SCS, two different interpretations existed in the history of RAN1 discussions. This was discussed in RAN1#104b-e [1] and RAN1#105-e [2], and it was concluded that the two different interpretations can exist in Rel-15, but for Rel-16, a working assumption was made to adopt interpretation 2 below. The main reasons for adopting interpretation 2 are that it is aligned with earlier RAN1 agreement and it is also aligned with the Type-1 HARQ-ACK codebook construction in TS 38.213.

***Conclusion:*** *(RAN1#104b-e)*

*For HARQ-ACK timing in Rel-15, in case UL SCS is larger than DL SCS, 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*

*Further discuss this issue for Rel-16 in future meetings.*

***Working Assumption*** *(RAN1#105-e)*

*For HARQ-ACK timing in Rel-16 with slot-based HARQ-ACK feedback, in case UL SCS is larger than DL SCS, k = 0 corresponds to the last UL slot that overlaps with the DL slot for the PDSCH.*

* *Further discuss the HARQ-ACK timing for sub-slot-based HARQ-ACK feedback*
* *FFS specification impact*

What remains open is the HARQ-ACK timing for sub-slot-based HARQ-ACK feedback. As discussed in [2], similar to slot-based HARQ-ACK feedback, two options are available:

*For HARQ-ACK timing in Rel-16 with sub-slot-based HARQ-ACK feedback,*

* *Option 1: k = 0 corresponds to the last UL sub-slot that overlaps with the PDSCH.*
* *Option 2: k = 0 corresponds to the last UL sub-slot that overlaps with the DL slot for the PDSCH.*

Option 1 is aligned with the following RAN1#97 agreement, while Option 2 is aligned with the working assumption that was made for slot-based HARQ-ACK timing in RAN1#105-e.

*Agreements: (RAN1#97)*

*For sub-slot-based HARQ-ACK feedback procedure, K1 is the number of sub-slots from the sub-slot containing the end of PDSCH to the sub-slot containing the start of PUCCH.*

* *Use UL numerology to define the sub-slot grid for PDSCH-to-sub-slot association.*
* *FFS: The configurable value range of K1 needs to be extended, and impact to related DCI field bitwidth.*
* *Note: It has been agreed that K1 is defined following R15 approach but in unit of sub-slot.*

This issue was discussed in [3]-[6] submitted to RAN1#106-e. A draft CR is also provided in [3].

Option 2 is preferred in [3][6], while Option 1 is preferred in [4][5]. The arguments for each option are summarized as follows:

* Option 1
  + Reduced latency in some cases (e.g. when PDSCH is at the beginning of the DL slot and the earliest symbols for HARQ-ACK feedback are UL symbols) compared to Option 2, as shown in Figure 1.
* Option 2
  + Consistent behavior between slot-based and sub-slot-based HARQ-ACK feedback timing
  + Principle of Type 1 HARQ-ACK codebook construction can be reused for sub-slot-based HARQ-ACK feedback.
  + Less gNB/UE complexity and less specification impact

Diagram

Description automatically generated

Figure 1 *k = 0* for Option 1 and Option 2

# 3 Email Discussions

## 3.1 First Round of Email Discussion

For HARQ ACK timing in Rel-16 with sub-slot-based HARQ-ACK feedback,

* Option 1: k = 0 corresponds to the last UL sub-slot that overlaps with the PDSCH.
* Option 2: k = 0 corresponds to the last UL sub-slot that overlaps with the DL slot for the PDSCH.

**Companies please indicate which option you support.**

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| --- | --- |
| **Option 1** | Nokia/NSB, Qualcomm, OPPO, vivo, CATT, HW/HiSi (slight preference), DOCOMO, Sharp, Intel, ZTE |
| **Option 2** | Intel (can accept), Apple, Ericsson, MTK |

**Companies please provide detailed reasons why you support Option 1 or 2.**

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| --- | --- |
| **Company** | **Comments** |
| Nokia, NSB | Option 1 to have the reduced latency. We should not forget that the main motivation in Rel-16 to introduce sub-slot PUCCH actually was to reduce the HARQ-ACK latency which would be now lost.  Actually, we don’t think that option one creates more specification changes as actually the current specs describe Option 1 (so changes will be needed for the slot-based decision, not the other way around)!  On the Type 1 CB, we anyhow need changes there so also here we don’t think there is a need for much different handling – moreover, this is not existing specifications yet (see AI 8.3.1.1 where we introduce this now in Rel-17) |
| Qualcomm | We support Option 1. As pointed out by Nokia, Option 1 is what we agreed in RAN1 Rel-16 URLLC, and is what’s been implemented in the spec (TS 38.213, v16.6.0).  On the type-1 CB, Rel-16 doesn’t support sub-slot based Type-1 HARQ-ACK CB. So we are not sure why this should be taken into account for a Rel-16 CR discussion (at this late stage). |
| OPPO | We support option 1. As commented by Nokia and QC, option 1 can reduce the HARQ feedback latency, which is the intention to introduce sub-slot based HARQ-ACK feedback in Rel-16. And we share similar view with QC that Rel-16 does not support sub-slot based Type-1 HARQ-ACK CB so some changes (if needed) can leave to Rel-17 HARQ-ACK AI. |
| vivo | Agree with Nokia, Qualcomm and OPPO. Option 2 is against the intention of sub-slot to reduce the HAQ-ACK feedback latency. Sub-slot based type-1 CB is not supported in Rel-16. |
| CATT | Same view as above. |
| HW/HiSi | We have a slight preference for Option 1, since it does not extent the feedback delay, which could be the case with Option 2, if the PDSCH is scheduled in the front-part of the slot. Additionally, Option 1 is aligned with the previous agreement. |
| DOCOMO | Option 1 should be supported based on the RAN1#97 agreement. We need to revert the agreement to support Option 2. |
| Samsung | At least, our preference is to have unified design regardless of whether slot-based or sub-slot-based HARQ-ACK feedback is configured. So, before deciding which option is supported for sub-slot based HARQ-ACK feedback, we would like to hear other companies’ view on this aspect firstly. |
| Sharp | Option 2 increases latency for sub-slot based HARQ-ACK reporting. Option 1 reduces the latency. |
| Intel | We see the motivation behind Option 2 and do not see the latency impact as significant. However, given that we have an explicit agreement from RAN1 #97 that points towards Option 1, it would be appropriate to go with Option 1. |
| Apple | We prefer Option 2 because we think the latency impact is minimal in practical network. In most cases, we would not see any difference in the latency. Only in the rare cases when the conditions are perfectly lined up, we see some impact on latency. Option 2 on the other hand allows a unified design between slot-based and sub-slot-based HARQ-ACK feedback. |
| Ericsson | Option 2.  The reason for the CR is not only for Type-1 HARQ-ACK CB. It is also needed for Type-2 CB in order to have a proper timing for CB construction. Hence, the arguments related to Type-1 HARQ-ACK CB for Rel-16 are not justified since Rel-16 does not support Type-1 CB for sub-slot.  The argument from latency is not clear to us. Why should Option 2 results in higher latency than Option 1?  If DL is on 15 kHz, and UL on 15 kHz configured with sub-slot of 7 symbols, we run in the same issue. The codebook construction would be rely on the duration and position of any scheduled PDSCH in a slot.  Hopefully the NW vendors consider this complexity.  Lastly, it is not preferred to have different approaches. Unified solution is always preferred. |
| ZTE | Slightly prefer Option 1. |
| MTK | We tend to agree with Ericsson and prefer Option 2. To us, it is better to apply a unified solution and pursue less gNB/UE complexity and less specification impact, although we understand Option 1 fits better with previous RAN1 agreement in RAN1 #97. |
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The TP for both slot-based and sub-slot-based HARQ-ACK feedback will be discussed together after this issue is concluded.

## 3.2 Second Round of Email Discussion

From the first round of email discussion, here are companies’ preferences:

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| **Option 1** | Nokia/NSB, Qualcomm, OPPO, vivo, CATT, HW/HiSi (slight preference), DOCOMO, Sharp, Intel, ZTE |
| **Option 2** | Intel (can accept), Apple, Ericsson, MTK |

Samsung prefers a unified solution between slot-based and sub-slot-based HARQ-ACK timing.

Given that majority companies prefer Option 1, here is the proposal for discussion:

### Proposal 1:

**For HARQ ACK timing in Rel-16 with sub-slot-based HARQ-ACK feedback, adopt Option 1.**

* **Option 1: k = 0 corresponds to the last UL sub-slot that overlaps with the PDSCH.**

**Companies please comment with detailed reasons if this proposal is not acceptable to you.**

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| **Company** | **Comments** |
| Nokia/NSB | Support |
| vivo | Support |
| ZTE | Support |
| Qualcomm | Support |
| HW/HiSi | Support |
| Samsung | Conditionally okay if option 1 can be supported for slot based HARQ-ACK feedback.  We share a similar concern raised by Sigen about different design between slot and sub-slot configuration.  Even though sub-slot based type-1 HARQ codebook is not supported in Rel-16, anyhow UE/gNB still need to calculate K1 value whenever a DCI scheduling PDSCH and corresponding HARQ-ACK PUCCH.  So, if a UE supports slot-based HARQ-ACK (LP) and sub-slot based HARQ-ACK (HP) simultaneously, this issue can be more complex. |
| Ericsson | We shared the same concern as Samsung with respect to Option 1.  In addition, and to clarify Signe’s question, consider the following example where dynamic HARQ-ACK codebook is applied. DL and UL both on 15 kHz but UL is configured with sub-slot of 7 symbols. (The scenario becomes similar to DL and UL with different SCS with higher SCS at UL)  As the example shows, following Option 1, depending on the resource allocation of each PDSCH in time in a slot,  the mapping to find the sub-slot for PUCCH would be different even PDSCHs are scheduled in the same DL slot and use same k1 value.  However, in Option 2, for any PDSCHs in scheduled in the same slot, the mapping to find a slot for PUCCH would depend only on k1 and the DL slot .    Clearly this makes scheduling unnecessarily complicated for NW vendors and we don’t see really the motivation and cannot support Option 1.  The added complexity with Option 1 compromises the benefits in flexible scheduling of PDSCH (same motivation for slot-based scheduling for DL and UL with different SCS with higher SCS at UL) .    I hope companies take these consequences into account for making decision. |
| MediaTek | We (MTK) still prefer Option 2, and suggest companies to check the nice figure provided by Ericsson (Sorour) to consider the trade-off we are paying here.    Having said that, we can be open on the possibility of taking Option 1 for progress if we are the only company objecting. |
| Qualcom | Honestly, we are a bit surprised/confused about the discussion about pros and cons of Option 1 and Option 2 in this thread.. A more appropriate time to have such discussions would be 2 years ago, before the agreement below was made in RAN1.  Such discussions were already concluded.  *Agreements: (RAN1#97)*  *For sub-slot-based HARQ-ACK feedback procedure, K1 is the number of sub-slots from the sub-slot containing the end of PDSCH to the sub-slot containing the start of PUCCH.*  ·        *Use UL numerology to define the sub-slot grid for PDSCH-to-sub-slot association.*  ·        *FFS: The configurable value range of K1 needs to be extended, and impact to related DCI field bitwidth.*  ·        *Note: It has been agreed that K1 is defined following R15 approach but in unit of sub-slot.*  Furthermore, another agreement that reinforces Option 1 was recently made in NR Rel-17 for subslot based PUCCH, see below.  Agreement (RAN1 #104b-e): Support Type-1 HARQ-ACK codebook for sub-slot based PUCCH configuration in Rel-17.   * The properties of the Type-1 HARQ-ACK codebook for sub-slot PUCCH at least includes that a PDSCH TDRA is associated with a UL /PUCCH sub-slot if the end of the PDSCH overlaps with the associated sub-slot determined by a k1 in the set of sub-slot timing values K1. * FFS: whether the PDSCH TDRA grouping is performed per DL slot or sub-slot   + Decide between PDSCH TDRA grouping per DL slot and sub-slot during RAN1#105-e   Unless Option 1 is broken, it is unclear to us why we should open this discussion again, and why we should revert the agreements in both Rel-16 and Rel-17 to go with Option 2. |
| Samsung2 | It is fact that option 1 is based on the agreement Qualcomm explained.  If there is no consensus in the proposal, option 1 still remains since option 2 is not in current specification.  It is also fact that there are an agreement for sub-slot based HARQ and a working assumption for slot based HARQ.  As I mentioned before, if we want to have unified solution, one of the agreement and the working assumption should be reverted. This is current situation.  Honestly, I have no idea on how we can move forward in one way or another.  If the current situation is not changed, may I ask is there any chance/discussion time to re-consider the working assumption for slot based HARQ?  From my understanding, current specification has the principle of option 1 for both slot and sub-slot based HARQ.  So, there is no specification impact at all. |
| ~~CATT~~OPPO | We support proposal 1 as we have indicated in the earlier comment. For the complexity issue mentioned for option 1 brought by Ericsson, we think this complexity is acceptable since UE/NW only needs to check the last symbol of PDSCH. Moreover, as mentioned by QC, the balance of latency reduction and complexity has already been discussed almost two years ago and the agreement is achieved in RAN1 #97, which is quite aligned with the motivation of the feature of sub-slot HARQ-ACK feedback. We fail to see there is any reason to revert the agreement. |
| MediaTek | As said before, we (MTK) can be open on the possibility of taking Option 1 for **sub-slot based HARQ** for progress if we are the only company objecting.  However, we can **NOT** accept to revert the working assumption for **slot-based HARQ**. Companies have extensive discussions on the **slot-based HARQ**in previous RAN1 meetings, and we think RAN1’s consideration to adopt Option 1 for **sub-slot based HARQ**is due to the application scenario of URLLC. **Changing slot-based HARQ  would also affect the scenario of eMMB**, which is **not** acceptable to us. |

After further discussion, the following was agreed.

### Agreement

**For HARQ ACK timing in Rel-16 with sub-slot-based HARQ-ACK feedback, irrespective of UL SCS and DL SCS, k = 0 corresponds to the last UL sub-slot that overlaps with the PDSCH.**

### Agreement

**Confirm the RAN1#105-e working assumption with the following modification:**

**For HARQ-ACK timing in Rel-16 with slot-based HARQ-ACK feedback, in case UL SCS is larger than DL SCS, k = 0 corresponds to the last UL slot that overlaps with the DL slot for the PDSCH.**

* **~~Further discuss the HARQ-ACK timing for sub-slot-based HARQ-ACK feedback~~**
* **FFS specification impact**

## 3.3 TP discussion

This section is to discuss the TP for the agreement made on the HARQ-ACK timing for slot-based HARQ-ACK feedback. Please check Proposal 2 and provide feedback.

### Proposal 2:

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

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| 9.1.2 Type-1 HARQ-ACK codebook determination  This clause applies if the UE is configured with *pdsch-HARQ-ACK-Codebook = semi-static*.  A UE does not expect to be configured with *pdsch-HARQ-ACK-Codebook = semi-static* for a codebook if a UE is provided *subslotLength-ForPUCCH* for the codebook.  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*, is a maximum value of *pdsch-AggregationFactor-r16* in *SPS-Config* or *pdsch-AggregationFactor* in *PDSCH-Config*; otherwise . The UE reports HARQ-ACK information for a PDSCH reception  - from DL slot to DL slot , if is provided by *pdsch-AggregationFactor* or *pdsch-AggregationFactor-r16* [6, TS 38.214], or  - from DL slot to DL slot , if the time domain resource assignment field in the DCI format scheduling the PDSCH reception indicates an entry containing *repetitionNumber,* or  - in DL slot , otherwise  only in a HARQ-ACK codebook that the UE includes in a PUCCH or PUSCH transmission in slot , where  - is a UL slot overlapping with the end of the PDSCH reception in DL slot if the UE is provided *subslotLengthForPUCCH* for the codebook; otherwise, is a UL slot overlapping with the end of the DL slot .  - 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 , 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-ACK  A 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 DL slot , the UE transmits the PUCCH in slot where 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 DL slot , the UE provides corresponding HARQ-ACK information in a PUCCH transmission within slot where 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 DL slot  or if the UE detects a DCI format indicating a SPS PDSCH release or indicating SCell dormancy through a PDCCH reception ending in DL slot , 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 DL slot , as described in clause 9.1.4, 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*, *dl-DataToUL-ACK-r16*, or *dl-DataToUL-ACKForDCIFormat1\_2*.  If the UE is provided *subslotLengthForPUCCH* for the codebook, is a UL slot that overlaps with the end of the PDSCH reception or with the end of 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; otherwise, is a UL slot that overlaps with the end of the DL slot for the PDSCH reception or the end of the DL slot for 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 > |

**Companies please provide comments on Proposal 2.**

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| **Company** | **Comments** |
| CATT | Thanks for the TP. We have two comments below.  For section 9.1.2, it is already clear from the second paragraph that sub-slot based Type-1 HARQ-ACK codebook is not supported. Therefore, we can consider slot-based HARQ-ACK feedback only and change the spec as follows.  - is a UL slot overlapping with the end of the ~~PDSCH reception in~~ DL slot  For section 9.2.3, we propose to delete “With reference to slots for PUCCH transmissions” since it does not apply any more.  ~~With reference to slots for PUCCH transmissions, i~~If the UE detects a DCI format scheduling a PDSCH reception ending in DL slot or if the UE detects a DCI format indicating a SPS PDSCH release or indicating SCell dormancy through a PDCCH reception ending in DL slot , 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 DL slot , as described in clause 9.1.4, 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*, *dl-DataToUL-ACK-r16*, or *dl-DataToUL-ACKForDCIFormat1\_2*. |
| MTK | Thanks for moderator’s efforts. We are fine with Proposal 2. |
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# 4 Outcome of the Email Discussion

# References

1. R1-2104105, Summary of email discussion [104b-e-NR-7.1CRs-04] on the correction for HARQ-ACK timing, Moderator (Apple Inc.), RAN1#104b-e, April 2021.
2. R1-2106301, Summary of email discussion [105-e-NR-7.1CRs-13] on the correction for HARQ-ACK timing in Rel-16, Moderator (Apple Inc.), RAN1#105-e, May 2021.
3. R1-2107063, Draft CR on Timing for slot-based and sub-slot-based HARQ-ACK Feedback, Ericsson, RAN1#106-e, Aug. 2021.
4. R1-2107266, Remaining issues on HARQ-ACK timing for sub-slot based HARQ-ACK feedback, OPPO, RAN1#106-e, Aug. 2021.
5. R1-2107681, Correction for HARQ-ACK timing in Rel-16, Huawei, HiSilicon, RAN1#106-e, Aug. 2021.
6. R1-2107713, Discussions on HARQ-ACK timing for sub-slot-based HARQ-ACK feedback in Rel-16, Apple, RAN1#106-e, Aug. 2021.