3GPP TSG-RAN WG1 Meeting #105-e R1-21xxxxx

e-Meeting, 19th – 28th May, 2021

Agenda Item: 8.2.3

Source: Moderator (Ericsson)

Title: FL Summary for [105-e-NR-52-71GHz-02] Email discussion/approval

Document for: Discussion, Decision

# 1 Introduction

This document summarizes the contributions made under the “Enhancements for PUCCH Formats 0/1/4” agenda item of the Rel-17 work item "Supporting NR from 52.6GHz to 71 GHz."

The updated WID [1] contains the following objective related to this agenda item:

- Support enhancement for PUCCH format 0/1/4 to increase the number of RBs under PSD limitation in shared spectrum operation.

The following email thread is assigned for discussion of this topic:

[105-e-NR-52-71GHz-02] Email discussion/approval on PUCCH format 0/1/4 enhancements with checkpoints for agreements on May 25, May 27 – Steve (Ericsson)

The following is an outline of the summary:

2 Frequency Domain Resource Mapping

2.1 Maximum number of RBs for Enhanced PF0/1/4

2.1.1 <1st Round Comments> Discussion Required

2.2 Configuration Granularity on Number of RBs

2.2.1 <1st Round Comments> Proposal 1

2.3 RE Mapping for Enhanced PF0/1/4 for 120 kHz SCS

2.3.1 <1st Round Comments> Proposal 2

3 Sequence Construction for Enhanced PF0/1

3.1 <1st Round Comments> Proposal 3

4 Rate matching for enhanced PF4

4.1 <1st Round Comments> Discussion Required

5 PUCCH Resource Sets Prior to RRC Configuration

5.1 Indication of Number of RBs

5.1.1 <1st Round Comments> Discussion Required

5.2 Subcarrier Spacing

5.2.1 <1st Round Comments> Discussion Required

5.3 Frequency Hopping Distance

5.3.1 <1st Round Comments> Discussion Required

5.4 Handling Potential RB Shortage

5.4.1 <1st Round Comments> Discussion Required

# 2 Frequency Domain Resource Mapping

## 2.1 Maximum number of RBs for Enhanced PF0/1/4

The following agreements were made in RAN1#104bis-e:

Agreement:

* The maximum values for the configured number of RBs, NRB, for enhanced PF0/1/4 are at least:
  + 12 RBs for 120 kHz SCS
  + 3 RBs for 480 kHz SCS
  + 2 RBs for 960 kHz SCS
* FFS: Whether or not the above values need to be revised to support larger values (and any associated signaling impact), e.g., to support lower UE Tx beamforming gain and/or larger UE EIRP and conducted power limits for different UE power classes, different from those in the agreed evaluation assumptions

Agreement:

For addressing the FFS from the prior agreement in RAN1#104bis-e on the maximum values for the configured number RBs, send an LS to RAN4 asking for feasible maximum values for UE\_EIRP and UE\_P for operation in 52.6-71 GHz.

The main open issue is whether or not the maximum number of RBs should be increased beyond the agreed values of 12/3/2 for 120/480/960 kHz SCS.

The following table provides a summary of company proposals on this topic.

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| --- | --- |
| **Company** | **Company Proposals** |
| Futurewei | ***Proposal 1: Once the final power limits and beamforming gains feedback from RAN4 are available, re-evaluation to capture the trends under different regional regulations is necessary, if the finalized values differ from the suggested values from RAN1.***  ***Proposal 2: The MIL trend not only varies according to the number of RBs used, but also according to the number of OSs. Therefore, evaluate different RB value sets for different number of OSs under PF1.***  ***Proposal 3: For better coverage, the gNB can configure a larger number of RB to carry UCI if smaller number of OSs is selected.*** |
| Intel | **Proposal 2: Depending on the LS reply from RAN4, RAN1 should discuss whether a proper framework is needed for the UE to implicitly or explicitly indicate its nominal beamforming gain in addition to the power class to the gNB.** |
| CATT | **Proposal 3 If RAN4 agree to support a larger set of maximum configurable number of RBs, two sets of maximum values for enhanced PF0/1/4 can be used.** |
| ZTE | **Proposal 1: Wait for the reply LS from RAN4 on maximum UE\_EIRP and UE\_P to determine the maximum number of PRBs.** |
| NTT DOCOMO | ***Proposal 1:*** *PUCCH format 2/3 may need to be enhanced according to the updated evaluation assumption for UE power limits depending on LS response from RAN4.* |
| Nokia | ***Observation 1:*** *Determining maximum value for configured RBs solely based on bandwidth needed for reaching maximum EIRP or conducted power limit may lead to impractically large PUCCH allocations*  ***Observation 2:*** *PUCCH format 2/3 configuration limit of 16 RBs can be seen as an upper limit for RB allocations considered for enhanced PUCCH format 0/1/4 with 120 kHz SCS* |
| OPPO | **Proposal 1: determine the maximum value for the UE conducted power and EIRP before determining the maximum values for the configured number of RBs.**  **Proposal 2: If RAN4 does not specify maximum values for UE conducted power and EIRP, regulatory power limits should be considered when determining the maximum values for the configured number of RBs.** |
| Huawei | ***Proposal 1: The maximum number of PRBs for the PUCCH is:***   * ***For 120 kHz SCS: 32*** * ***For 480 kHz SCS: 8*** * ***For 960 kHz SCS: 4*** |
| Apple | ***Proposal 3:*** *For PF2 and PF3, a restriction on the minimum number of RBs transmitted for each SCS should also be specified subject to waveform specific limitations for PF3.* |
| Interdigital | ***Proposal 1:*** *It is preferred to hold the discussion on max(NRB) until receiving RAN4’s response on the LS.* |
| MediaTek | Proposal 1: The maximum values of for SCS of 120 KHz, 480 KHz, and 960 KHz are determined using and values provided by RAN4, and under the assumption that . |
| Ericsson | Proposal 1 RAN1 should wait for feedback from RAN4 on feasible pairs of (UE\_EIRP, U\_P) values for the 52.6 – 71 GHz band before concluding on whether or not to increase the maximum number of RBs beyond 12 / 3 / 2. |

While some companies propose supporting larger values of N\_RB already now, many companies suggest to wait for feedback from the RAN4 before making a decision. Since RAN1 went to the trouble of sending an LS, and RAN4 will discuss it in their concurrent meeting, it is reasonable not to short circuit this process.

However, one discussion that we could have while awaiting feedback is whether or not RAN1 should try to narrow the scope of the potential increase to the number of RBs. For example, some companies have observed a relationship to PF2/3 for which the maximum number of RBs that can be configured is 16. While it is outside the scope of this WI to make enhancements to PF2/3, a natural question is whether or not it makes sense to support a value larger than 16 for enhanced PF0/1/4? It would be useful to discuss this while awaiting feedback.

**FL Recommendation Wait for feedback on the LS to RAN4 before making a decision on whether or not to increase the maximum number of RBs for enhanced PF0/1/4 beyond the values 12 / 3 / 2 agreed so far.**

### 2.1.1 <1st Round Comments>

Please provide your company view on the above FL recommendation as well as the following question:

**Question**: What is your view on the following alternatives, assuming that RAN1 still awaits feedback on the LS to RAN4

* Alt-1: RAN1 limits the discussion on potential increased max(N\_RB) to values no larger than 16 RBs (same maximum as for PF2/3 in Rel-15).
* Alt-2: RAN1 does not limit the discussion

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| **Company** | **View/Position** |
| Intel | We prefer Alt-2, and we would refrain from posing any limitations. Perhaps, as discussed in the prior meeting, RAN1 could at least discuss the minimum and practical range of values for the Tx beamforming gain. |
| LG | We support the Alt-2. We do not see the technical reasons to restrict the number of RB (N\_RB) as the same as the maximum for PF2/3 in Rel-15. It is important that the maximum N\_RB should be determined to support enough coverage of PF0/1 in the above 52.6GHz. |
| OPPO | Support Alt-2. The maximum PUCCH bandwidth should be calculated based on the maximum achievable transmit power. It is more reasonable to wait for RAN4 feedback. While 16 RB bandwidth limit for PF 2/3 was adopted in R15, which was not motivated by the same motivation that we talk about here. Therefore, we don’t think that 16 RB bandwidth limit for PF 2/3 should be aligned with bandwidth limit for PF 0/1/4. |
| Nokia, NSB | Support Alt-1. We do not see practical reasons to support wider allocations for PF0/1 carrying up to 2 UCI bits, while PF2/3 used for larger UCI payloads are limited to 16 RBs. |
| Futurewei | We prefer Alt-2 and it would need to wait for RAN4’s decision on whether or not to increase the number of RBs for enhanced PF0/1/4. Regarding the maximum RB 16 for PF2/3, the existing value is not motivated by the same reason for PF0/1/4, so it is not a deciding factor for the maximum RBs of PF0/1/4 to be determined. If necessary, the maximum value for all PF0/1/2/3/4 can be extended beyond 16. |
| vivo | Our slight preference is Alt-1 as we don’t see a clear benefit with a larger than 16 N\_RB for PF0/1/4. |

## 2.2 Configuration Granularity on Number of RBs

The following agreement was made in RAN1#104bis-e:

Agreement:

Down select to one of the following two alternatives for the configuration of the number of RBs, , for enhanced PUCCH formats 0/1/4:

* Alt-1:
  + For enhanced PF0/1
    - Support configuration of all integer values in the range [1 .. max()] for each SCS
  + For enhanced PF4
    - Support configuration of all integer values in the range [1 .. max()] for each SCS that fulfill the requirement where is a set of non-negative integers.
* Alt-2:
  + Same as Alt-1, but with coarser granularity, i.e., not all integer values of can be configured
  + FFS: Which values of are supported values in the range [1 .. max()]

The main open issue is what should be the granularity of the configured values, and two alternatives were identified in the last meeting.

The following table provides a summary of company proposals on this topic.

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| --- | --- |
| **Company** | **Company Proposals** |
| vivo | **Proposal 5: For the configuration of the number of RBs, , for enhanced PUCCH formats 0/1/4, the alternative 1 is supported.** |
| Futurewei | ***Proposal 4: To address the dynamic HARQ-ACK codebook size it seems beneficial to consider the number of RBs be indicated by the DCI for better coverage or power saving. In this case, coarser granularity indication is beneficial for DCI overhead reduction consideration.***    ***Proposal 5: Support configuration with a coarser RB granularity for PF0/1/4. Recommend candidate RB value sets contain the following options:***   * ***Option 1: {1, 2, 4, 8, 16, 22} for SCS 120kHz, {1, 2, 4, 6} for SCS 480kHz, and {1, 2, 3} for SCS 960kHz.*** * ***Option 2: {1, 2, 4, 6, 8, 12, 16, 22} for SCS 120kHz, {1, 2, 4, 6} for SCS 480kHz, and {1, 2, 3} for SCS 960kHz.*** * ***Option 3: {1, 2, 4, 6, 8, 12, 16, 22} for SCS 120kHz, {1, 2, 3, 4, 5, 6} for SCS 480kHz, and {1, 2, 3} for SCS 960kHz*** |
| CATT | **Proposal 5 For enhanced PF0/1, Alt-2 with coarser granularity is preferred for the configuration of the number of RBs.** |
| ZTE | **Proposal 2: The allowed values of N\_RB within the range** [1 .. max()] **can be flexible, Alt-1 is preferred in PRB number configuration.** |
| NTT DOCOMO | ***Proposal 4:*** *All integer values for PUCCH format 0/1 and all integer values that fulfill the requirement where is a set of non-negative integers for PUCCH format 4 (Alt-1 in RAN1#104bis-e agreement) should be supported.* |
| Nokia | ***Proposal 3:*** *In case of dedicated PUCCH resource configuration, Alt-1 is supported. In case of common PUCCH resource set, Alt-2 is supported.* |
| Qualcomm | **Proposal 2: For the configuration of the number of RBs, , for enhanced PUCCH formats 0/1/4, we support Alt-2, and further propose:**   * + **For enhanced PF0/1/4, supported number of RBs set is [1,2,3,4,6,8,12] for 120kHz SCS** |
| LGE | **Proposal #2: For the allowed values of NRB, the positive integer values between the min/max NRB can be used for PF0/1 while the allowed values of NRB between the min/max NRB for PF4 can be obtained by applying the DFT constraint.** |
| Huawei | ***Proposal 2: Adopt Alt. 1 for the granularity of the configuration of the number of RBs, , for enhanced PUCCH formats 0/1/4.*** |
| Apple | ***Proposal 1:*** *For enhanced PUCCH formats 0/1/4 the choice of selecting all valid integer values in the range [1 .. max( )] for each SCS vs a subset of the values should depend on the maximum value of N\_RB estimated after the reply from RAN4.* |
| Samsung | **Proposal 2: Support configuration of all integer values in the range of [1 .. max()] per SCS, for PUCCH format 0/1. Support configuration of all integer values in the range [1 .. max()] for each SCS that fulfills the requirement where is a set of non-negative integers for PUCCH format 4.** |
| Interdigital | ***Proposal 2:*** *All integer values for PUCCH format 0/1 and all integer values which fulfill the requirement for PUCCH format 4 (Alt-1) are supported.* |
| Spreadtrum | ***Proposal 1: Support the configuration of coarser granularity for the numbers of contiguous RBs for enhanced PUCCH format 0/1/4 for 120/480/960 kHz SCS.***  ***Proposal 2: A set like {1, 2, 4, 6, 12} for 120 kHz SCS，{1, 2, 3} for 480 kHz SCS and {1, 2} for 960 kHz SCS can be supported as the candidate values.*** |
| Ericsson | **Proposal 2 Support Alt-1 in the agreement from RAN1#104bis-e on the granularity of the configuration of the number of RBs** |

The following is a summary of support for the two alternatives:

* Alt-1: vivo, ZTE, NTT DOCOMO, Nokia, LGE, Huawei, Samsung, Interdigital, Ericsson
* Alt-2: Futurewei, CATT, Qualcomm, Spreadtrum

Clearly a large majority of companies support Alt-1. Proponents of Alt-1 argue that there is a need for configuration flexibility due to operation in different regions and operation with different UE capabilities, and that the additional RRC overhead compared to Alt-2 is very small. Furthermore, for PF2/3, any values in the range 1 .. 16 can be configured. Proponents of Alt-2 argue that the transmit power scales with the log of N\_RB, so not all values of N\_RB are needed.

Do proponents of Alt-2 have a strong view? If not, then can the following proposal be acceptable as a step forward?

**Proposal 1 If RAN1 agrees that max(N\_RB) is no larger than 16, support Alt-1. Otherwise, further discuss Alt-1 vs. Alt-2.**

### 2.2.1 <1st Round Comments>

Please provide your company view on Proposal 1.

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| **Company** | **View/Position** |
| Intel | We are OK with the proposal, and to further consider Alt-2 if we conclude that the max{NRB}>16. |
| LG | We support the Proposal 1 and share the same view with Moderator. |
| OPPO | OK, but this proposal should be applied for UE dedicated RRC configuration. |
| Nokia, NSB | We are fine with the proposal when applied for UE dedicated RRC configuration. |
| Futurewei | Agree with the moderator’s proposal. Consider extending the maximum number of RBs for all formats, i.e., PF0/1/2/3/4. |
| vivo | OK with the proposal.  Our preference is Alt-1. We don’t see a strong motivation of Alt-2 as the overhead reduction is marginal but flexibility is reduced. |

## 2.3 RE Mapping for Enhanced PF0/1/4 for 120 kHz SCS

The following agreements were made at RAN1#104-e and RAN1#104bis-e:

Agreement:

For enhanced (multi-RB) PUCCH Formats 0/1/4 for 120/480/960 kHz SCS, support allocation of N\_RB contiguous RBs

* FFS: Values of N\_RB for each SCS
* For 480/960 kHz SCS, all REs within each RB are mapped
  + Note: PRB and sub-PRB interlaced mapping is not considered further
* For 120 kHz SCS, further discuss the following two alternatives:
  + Alt-1: All REs within each RB are mapped
    - Note: PRB and sub-PRB interlaced mapping is not considered further
  + Alt-2: Subset of REs within each RB are mapped (sub-PRB interlaced mapping)

Agreement:

User-multiplexing can be considered but as lower priority compared to maximum isotropic loss for PUCCH as a design criterion.

The main open issue is for the case of 120 kHz SCS, which RE mapping approach should be supported:

* Alt-1: All REs within each RB are mapped
  + Note: PRB and sub-PRB interlaced mapping is not considered further
* Alt-2: Subset of REs within each RB are mapped (sub-PRB interlaced mapping)

The following table provides a summary of company proposals on this topic.

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| **Company** | **Company Proposals** |
| vivo | Proposal 2: For enhanced PUCCH format 0/1, for 120 kHz SCS, we support alt 2 for RE mapping.  Proposal 3: For UCI of enhanced PUCCH format 4, all REs within each RB are mapped is preferred for 120kHz SCS.  Proposal 4: For DMRS of PUCCH format 4, the sub-PRB interlaced mapping should be supported. |
| Intel | **Proposal 1: For the enhanced (multi-RB) PUCCH formats 0/1/4 for 120 kHz SCS all REs within each RB are mapped.** |
| ZTE | **Proposal 3: In 52.6GHz-71GHz frequency band, PUCCH should be mapped into all REs within the PRBs allocated.** |
| Nokia | ***Proposal 2:*** *All REs within each RB are mapped for enhanced PUCCH format 0/1/4.* |
| OPPO | **Proposal 4: For 120 kHz SCS, adopt sub-PRB mapping instead of full-PRB mapping, where only 1 RE is mapped in a RB.** |
| LGE | **Proposal #1: For enhanced PUCCH formats 0/1/4 for 120 kHz SCS, the PRB and sub-PRB interlaced mapping should not be considered further** |
| Huawei | ***Proposal 3: Sub-PRB interlaced mapping is not introduced for 120 kHz SCS.*** |
| Apple | ***Proposal 2:*** *To ensure consistent design across all SCSs, for 120 kHz SCS, all REs within each RB are mapped.* |
| Samsung | **Proposal 1: Support unified solution for enhanced PUCCH format 0/1/4 based on contiguous multi-full PRB allocation for 120/480/960KHz.** |
| WILUS | * *Proposal 1: The interlaced or sub-PRB interlaced design for PUCCH format 0/1/4 seems not necessary to apply to 60GHz unlicensed spectrum from the perspective of power boosting in the new numerologies, i.e., 480kHz, 960kHz, and 120kHz SCS.* * *Even for 120kHz SCS case, we support Alt-1.*   + *Alt-1: All REs within each RB are mapped.*     - *Note: PRB and sub-PRB interlaced mapping is not considered further.* |
| Spreadtrum | ***Proposal 3: For enhanced (multi-RB) PUCCH Formats 0/1/4 for 120 kHz SCS, support allocation of N\_RB contiguous RBs in which all Res within each RB are mapped. Sub-PRB interlaced mapping is not considered further.*** |
| Ericsson | **Proposal 4 Do not support sub-PRB allocations for Rel-17 PUCCH.** |

The following is a summary of support for the two alternatives:

* Alt-1: Intel, ZTE, Nokia, LGE, Huawei, Apple, Samsung, WILUS, Spreadtrum, Ericsson
* Alt-2: vivo, OPPO

Clearly, there is an overwhelming majority of companies supporting Alt-1. Compared to last meeting, more companies have evaluated Alt-1 vs. Alt-2. The following is a high level summary of company evaluations:

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| **Company** | **Evaluation summary** |
| vivo | * PF0   + Evaluated multiplexing of 2 UEs     - Alt 1-1: FDM (different PRBs)     - Alt 1-2: Sequence multiplexing     - Alt 2-1: FDM (different combs in Comb-2 pattern)   + Comparable MIL performance for Alt 1-2 and Alt 2-1 if UE powers are balanced   + Alt 2-1 vs. Alt-1-2 has a 2-3 dB MIL gain in US/SK if UE powers are imbalanced (Alt 2-1 and Alt 1-2 have comparable MIL in Europe) * PF4   + Evalued a hybrid mapping scheme for PF4:     - Full-PRB mapping for UCI (Alt-1) + Sub-PRB mapping for DMRS (Alt-2)   + MIL gain of -0.3 – 2 dB (dependent on payload, delay spread) compared to Alt-1 |
| Intel | * PF0   + MIL evaluated in US, Europe, SK   + Compared Alt-1 vs. Alt-2 (Comb-2 pattern) for two different sequence constructions (single long sequence, repeated sequence + CSC)   + N\_RB ranges from 0 .. 40   + No gains found for Alt-2 |
| ZTE | * PF0   + MIL evaluated in SK   + Compared Alt-1 vs. Alt-2 (1 or first 6 REs mapped per PRB)   + Showed larger MIL for Alt-1 |
| OPPO | * PF0   + 12 RBs   + 1 RE per PRB mapped   + Comparable MIL between Alt-1 and Alt-2 (within 0.1 dB) |
| Ericsson | * PF0   + 2,4,6,8,10,12 RBs   + Comb-2 pattern for Alt-2   + At best (depending on # of RBs and delay spread), MIL of Alt-2 is comparable to Alt-1 in all regions (US,EU,SK) |

Observations based on reported evaluations:

* For PF0/1 using the agreed evaluation assumptions based on single user, it has been demonstrated that the MIL of Alt-1 and Alt-2 are generally comparable. Two companies have shown that MIL of Alt-1 can exceed the MIL of Alt-2.
* For PF0/1 with 2 multiplexed users, one company has demonstrated comparable MIL performance if the received powers of the 2 users are balanced. If the received powers are imalanced, Alt-2 can offer a gain in MIL.
* One company has evaluated PF4 with a hybrid RE mapping scheme: Alt-1 for UCI + Alt-2 for DMRS and found a gain in MIL.

Proponents of Alt-1 state the following:

* Alt-1 is preferred on the basis of having a uniform design for all SCSs (120, 480, 960 kHz)
  + There are strong concerns about implementation complexity and specification complexity from supporting 2 different RE mapping approaches
  + The moderator observes that if Alt-2 is supported for initial access, then it will be mandatory, i.e., it cannot be a UE capability
* While Alt-2 potentially offers improved user multiplexing, this should not be a design criterion due to the lack of opportunity to find users to multiplex in narrow beams used in 52.6 – 71 GHz
* While Alt-2 potentially offers improved spectral efficiency when compared to Alt-1 on the basis of the same number of RBs, if there are no users to multiplex, the unused REs of Alt-2 cannot be used for other purposes since sub-PRB interlacing is not supported for PUSCH, PRACH, and SRS
* Alt-2 is not preferred due to additional signaling overhead of indicating the resource mapping

Proponents of Alt-2 state the following:

* Alt-2 is preferred on the basis of improved user multiplexing
* Alt-2 is preferred on the basis of better spectral efficiency

In summary, since there is not a clear advantage in terms of coverage between Alt-1 and Alt-2, the decision point comes down to whether or not potentially improved user multiplexing is worth the cost in implementation/specification complexity of supporting two different RE mapping schemes. Given that companies have had two meetings to consider and evaluate the two alternatives, and that there has not been a shift in company positions, the FL recommends that a decision on down-selecting between Alt-1 and Alt-2 should be made in this meeting.

**Proposal 2 For enahanced PF 0/1/4 for 120 kHz, downselect to one of Alt-1 and Alt-2 in this meeting. The decision should be based on the consideration of implementation/specification complexity vs. user multiplexing.**

### 2.3.1 <1st Round Comments>

Please provide your company view Proposal 2.

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| **Company** | **View/Position** |
| Intel | Our view is to support Alt-1 only. Another important thing that we would like to emphasize is that based on our simulation campaign Alt-2 does not bring any gain compared to Alt-1, and furthermore even if in some cases the related MILs are comparable the current calculation does not account for the potential maximum transmit power reduction due to inter-modulation distortions (IMD) from interlace design, which we expect would further increase the coverage loss of Alt-2. |
| LG | We support Alt-1 and share the view with Intel. The benefits of Alt-2 are unclear when compared to Alt-1, and the majority of companies support Alt-1 in observations based on the evaluation. Moreover, as Intel pointed out, the RAN4 work may be increased due to the intermodulation distortions (IMD) from interlace design. For PF4, the Alt-1 is also preferred in terms of the unified RE mapping scheme for PF0/1/4. |
| OPPO | We support Alt-2 with the following technical reasons.  Alt-2 posseses multiple advantages over Alt-1 for initial access.  **Advantage 1**: when N\_RB is large, Alt-1 will occupy more bandwidth of intial UL BWP to allocate PUCCH resource for PUCCH resource index rPUCCH ranging from 0 to 15. As shown in the figure below, for N\_RB=12, the PUCCH resource occupies  96 RB (assuming NCS=2), while for Alt-2, the occupied number of PRB can be reduced to 12, which is a factor of 8 redcution. The benefit becomes more significant when the PUCCH symbol length increases. This can nicely address the RB shortage issue raised in section 5.4.    **Advantage 2**: with Alt-2, due to the multiplexing gain, one set of N\_RB resource can already support rPUCCH ranging from 0 to 15. In this case, the resulting frequency hopping distance between different UEs will remain equal. This is not the case with Alt-1, as illustrated in our figure. In this case, with Alt-1, the coverage is not balanced among differernt rPUCCH values. This issue has also been raised in section 5.3 and further enhancements are proposed by proponents. But the enhancement may unforturnately lead to a reduced hopping distance. The advantage of Alt-2 is that it can keep the maximum and balanced hopping distance among different UEs or among different rPUCCH values.  In summary, Alt-2 has multiplexing benefits over Alt-1, many companies dispute that the multiplexing benefit is not important. However, the issues raised in section 5.3 and 5.4 are all originated from the issue due to the lack of UE multiplexing capacity. Thus, we truly believe that multiplexing benefit is very important. |
| Nokia, NSB | We support Alt-1 only. Alt-2 leads to simultaneous use of interlaced and non-interlaced mapping, which complicates multiplexing and was avoided even in Rel-16 NR-U. |
| Futurewei | We prefer Alt-1 at least for PF0/1. The sub-PRB mapping for DMRS of PF4 may be an FFS for more inputs to be available. |
| vivo | For PF 0/1, the MIL performance of both Alt-1 and Alt-2 are comparable for single UE. When UE multiplexing is considered, there’s MIL performance gain of Alt-2 over Alt-1 espeacially for power imbanlance case. We’d like to emphasize that power imbanlance case may be typical for edge UEs where MIL gain is much desired particulary for PF 0/1.  On the argument against 2 RE mapping methods for different SCS, the point we want to make is that MIL (coverage) gain is more important for 120 kHz compared to other SCS. With the demonstrated MIL gain, we do think it justifiying different RE mapping for different SCS. On the criteria of a uniform design, it may be nice to have but we don’t think it should be the deciding factor as otherwise no need to spend two meetings evaluating all these MIL performance to begin with.  On the argument of implementation/specification complexity, it would be better for us to understand if companies can provide some analysis of how much extra implementation complexity.  With respect to UE multiplexing, during last meeting discussion, many companies assume it should be gNB choice whether to multiplex UEs. If system allows UE multiplexing and there’s a chance to multiplex UEs, then we found it difficult to understand the reason that a design should not consider UE multiplexing which is also against the agreement from last meeting.    One more point, as we showed and proposed in our contribution, DMRS RE mapping for PF 4 should be sub-PRB interlaced based on the observed MIL gain. Note that UCI data need to go through DFT precoding and OCC before mapped to RE while DMRS will go directly to RE mapping. So DMRS sub-PRB RE mapping is actually aligned with UCI data (i.e. comb structure in frequency domain) for PF 4 as we illustrated in Figure 11 of R1-2106065. |

# 3 Sequence Construction for Enhanced PF0/1

The following agreements were made in RAN1#104-e and RAN1#104bis-e:

Agreement:

* For enhanced PF0/1, support Type-1 low PAPR sequences. Further study and strive to select one of the following alternatives:
  + Alt-1: A single sequence of length equal to the total number of mapped REs of of the PUCCH resource is used. Cyclic shifts for PF0/1 are defined in the same way as Rel-16 for the case that *useInterlacePUCCH-PUSCH* is not configured.
  + Alt-2: A single sequence of length equal to the number of mapped REs per RB of the PUCCH resource is used, and the sequence is repeated in each RB. At least the following scheme is considered for PAPR/CM reduction:
    - Cycling of cyclic shifts across RBs in a similar way as for Rel-16 for PF0/1 for the case that *useInterlacePUCCH-PUSCH* is configured
* At least the following aspects should be considered in the study
  + Coverage (maximum isotropic loss (MIL)), including
    - Required SNR to fulfil PUCCH detection criterion
    - PAPR/CM as a function of N\_RB
  + Specification impact

Agreement:

User-multiplexing can be considered but as lower priority compared to maximum isotropic loss for PUCCH as a design criterion.

For the PF0/1 sequence, the main open issue is which sequence construction method should be supported:

* Alt-1: A single long sequence
* Alt-2: Sequence repeated in each RB + cyclic shift cycling for PAPR/CM mitigation

The following table provides a summary of company proposals on this topic.

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| --- | --- |
| **Company** | **Company Proposals** |
| vivo | **Proposal 1:** **For enhanced PUCCH format 0/1, the alt 1 of a single sequence of length equal to the total number of mapped REs of the PUCCH resource is preferred.**  **Proposal 10：For a single sequence of length equal to the total number of mapped REs of the PUCCH resource, the cyclic shift should be adapted with the length of the sequence at least for PUCCH format 0/1.** |
| Intel | **Proposal 3: For PUCCH format 0 and 1, the sequence is generated by using a Type-1 low PAPR sequence of length equal to the number of subcarriers over which the PUCCH spans across.** |
| Lenovo/MoM | ***Proposal 2: For NR operation between 52.6 GHz and 71 GHz, Rel 15 based long sequence should be considered for PUCCH formats 0/1 for mapping to multiple RBs.*** |
| CATT | Proposal 2 For enhanced PUCCH format 0/1 sequence, Alt1 (a single long sequence) is preferred to keep similar CM for sequences with different lengths.  Proposal 4 If a single long sequence is used for PUCCH format 0/1, multiplexing users with misaligned RB allocations can be avoided by gNB to ensure the detection performance. |
| ZTE | **Proposal 5: Regarding the PUCCH format 0/1 sequence type selection, Alt1 (a single long sequence) is preferred**  **Proposal 4: For PUCCH format 0/1/4, PRB misalignment issue can be left to gNB implementation.** |
| NTT DOCOMO | ***Proposal 2:*** *According to the evaluation results of Cubic Metric, required SNR on sequence detection and the MIL performance with sequence designs of Alt-1 and Alt-2, Alt-1* *should be supported as the PUCCH format 0/1 base sequence design with multiple RBs.* |
| Nokia | ***Proposal 1:*** *Support Alt-1 sequence construction: a single sequence of length equal to the total number of mapped REs for PUCCH Format 0/1 resources.*  ***Observation 3:*** *We do not see a need for supporting multiplexing of users with misaligned RB allocations with enhanced PUCCH formats 0/1.* |
| Sony | **Proposal 1: Since the MIL criterion alone cannot be used to down select between Alt-1 and Alt-2, consider UE multiplexing for down selection between Alt-1 and Alt-2.**  **Proposal 2. Given that in practice, Alt-1 and Alt-2 display the very similar performance in terms of MIL, support Alt-2 to enable efficient multiplexing of UEs with different configured values of .** |
| OPPO | **Proposal 3: Adopt long sequence for PUCCH format 0 and format 1 when N\_RB>1.** |
| Qualcomm | **Proposal 1: Support Alt-2 for base sequence type when PUCCH format 0/1 occupies more than one RB.** |
| LGE | **Proposal #4: Considering better MIL performance and improved coverage of multi-PRB based initial PUCCH for the specific RB range (e.g., NRB around 12-16), support Alt-2 (a single sequence of length equal to the number of mapped REs per RB with the step size ∆ = 5 for the cycling of cyclic shifts across RBs) for the sequence type for enhanced PUCCH format 0/1 in 60 GHz.** |
| Apple | ***Proposal 4:*** *For enhanced PF0/1, a single Type-1 low PAPR sequence of length equal to the total number of mapped REs of the PUCCH resource is used. Cyclic shifts for PF0/1 are defined in the same way as Rel-16 for the case that useInterlacePUCCH-PUSCH is not configured.* |
| Samsung | **Proposal 3: Support Alt-2 (Rel-16 NR-U short sequence with repetition) for PUCCH format 0/1.** |
| WILUS | * *Proposal 2: For low PAPR sequence for enhanced PUCCH format 0/1 (PF0/1), we support Alt-2 that a single sequence of length equal to the number of mapped REs per RB of the PUCCH resource is used, and the sequence is repeated in each RB with cycling of cyclic shifts across RBs in a similar way as for Rel-16 for PF0/1.* |
| Interdigital | ***Proposal 3:*** *It is preferred to support a single sequence of length equal to the total number of mapped REs of the PUCCH resource (Alt-1) for PUCCH format 0/1* |
| Spreadtrum | ***Proposal 4: For enhanced PF0/1, Alt -2 should be supported in order to reduce the impact of the specification.*** |
| MediaTek | Proposal 2: Alternative 1 should be adopted as the base sequence design for enhanced PUCCH format 0/1. |
| Ericsson | Proposal 3 In the agreement from RAN1#104-e on sequence construction for enhanced PF0/1, support Alt-1, i.e., reuse the Rel-15 rules to select base sequences based on Low-PAPR sequence Type-1 defined in 38.211 Section 5.2.2. Do not support repeated sequences with cyclic shift cycling (Alt-2). |

The following is a summary of support for the two alternatives:

* Alt-1: vivo, Intel, Lenovo(?), CATT, ZTE, NTT DOCOMO, Nokia, OPPO, Apple, Interdigital, MediaTek, Ericsson
* Alt-2: Sony, Qualcomm, LGE, Samsung, WILUS, Spreadtrum

Clearly, there a majority of companies support Alt-1; however, consensus cannot be declared yet. The following is a high level summary of company evaluations comparing Alt-1 vs. Alt-2.

|  |  |
| --- | --- |
| **Company** | **Evaluation summary** |
| ZTE | * Alt-1 and Alt-2 have comparable MIL performance for 120 kHz * Alt-1 has larger MIL for 480/960 kHz   + 1.5 dB gain for 3 RBs for 480 kHz   + 1 dB gain for 2 RBs for 960 kHz |
| Intel | * Alt-2 performance never exceeds Alt-1 for 120 kHz * For large number of RBs, Alt-1 performance significantly outperforms Alt-2 |
| DOCOMO | * Alt-1 vs. Alt-2 MIL comparison varies – hard to draw a conclusion * Moderator question: For 1 RB, it seems as though Alt-1 and Alt-2 should have the same performance? |
| Nokia | * Alt-1 shows 0.3 – 0.9 dB gain in coverage vs. Alt-2 for small RB allocations   + 120 kHz: Gain in Europe   + 480/960 kHz: Gain in all regions |
| Ericsson | * 480kHz:   + US/SK: Alt-1 has 1.5 dB (US) larger MIL for 3 RBs; comparable MIL for 1,2 RBs   + Europe: Alt-1 has 0.8 – 1.3 dB (Europe) larger MIL for 2 and 3 RBs; comparable MIL for 1 RB |
| Sony | * Comparable MIL for Alt-1 and Alt-2 for 120 kHz SCS * For 480 kHz, Figure 3 shows that one can achieve approximately 1.5 dB larger coverage with Alt-1 compared to Alt-2 (difference in P\_max between intersection point of solid green / dash-dot black line and intersection point of solid green / dashed red line) |
| Qualcomm | * 120 kHz: Comparable achievable power for Alt-1 and Alt-2 * 480 kHz: Alt-1 can achieve 1.5 dB higher power for 3 RBs (comparable power for 1,2 RBs) * 960 kHz: Alt-1 can achieve 0.7 dB higher power for 2 RBs (comparable power for 1 RB) * For 120 kHz, if UE\_EIRP is increased to 40 dBm (with 6 dBi TxBF), Alt-2 can achieve ~1 dB larger Tx power if the maximum # of RBs is increased to 14 |

Observations based on contributions and reported evaluations:

* Spec complexity
  + Both Alt-1 and Alt-2 can be seen as extensions of Rel-15 or 16, so no real difference in spec complexity
  + Alt-1: Used for DMRS of PF3 in Rel-15/16
  + Alt-2: Used for PF0/1 in Rel-16 when interlacing configured
* Detection performance (required SNR to achieve target error rate)
  + No real difference between Alt-1 and Alt-2
* MIL performance / achievable transmit power
  + 120 kHz SCS
    - Alt-1 has <1 dB gain vs. Alt-2 for small number of RBs in Europe
    - Alt-1 and Alt-2 have comparable performance in US/SK for up to 12 RBs
  + 480 kHz SCS
    - For 3 RBs in US/SK: Alt-1 has 1.5 dB gain vs. Alt-2
    - For 2 or 3 RBs in Europe: Alt-1 has ~1 dB gain vs. Alt-2
    - For 2 RBs in US/SK: Comparable performance between Alt-1 and Alt-2
  + 960 kHz SCS
    - 2 RBs
    - 1 RB: Comparable performance
  + If UE\_EIRP is increased to 40 dBm
    - For 120 kHz in US/SK: Alt-2 has ~1 dB gain vs. Alt-1 for 14 RBs
* User multiplexing
  + Some companies observe that Alt-2 offers better opportunities for multiplexing users with misaligned RB allocations, where "misaligned" also includes users with different number of RBs.
  + Other companies refer to the above agreement from RAN1#104bisi-e that user-multiplexing has lower priority as a design criterion compared to MIL

In summary, the decision point on Alt-1 vs. Alt-2 basically comes down to coverage vs. user multiplexing:

* Alt-1:
  + Improved coverage vs. Alt-2 for 480/960 kHz SCS in all regions
  + Comparable coverage vs. Alt-2 for 120 kHz SCS in all regions
* Alt-2:
  + Improved user multiplexing possibility vs. Alt-1
  + If UE\_EIRP increased to 40 dBm and max(N\_RB) is extended
    - Improved coverage vs. Alt-1 for 120 kHz SCS in US/SK for 12 .. 14 RBs
    - Degraded coverage vs. Alt-1 for 480/960 kHz in all regions

**Proposal 3 For enahanced PF 0/1/4 for 120 kHz, downselect to one of Alt-1 and Alt-2. The decision should be based on consideration of coverage vs. user multiplexing.**

## 3.1 <1st Round Comments>

Please provide your company view Proposal 3.

|  |  |
| --- | --- |
| **Company** | **View/Position** |
| Intel | We support Alt-1, but we are OK to wait until we conclude that the max{NRB} needed is larger than 16. For larger NRB, Alt-2 is substantially impacted in terms of CM, and  except for some limited cases, the loss compared to Alt-1 is constantly larger than 1/2 dB, and increases as the number of PRBs increases. |
| LG | It is important that the multi-PRB (i.e., NRB larger than 1) based PUCCH should be supported for the initial PUCCH resource considering the coverage of PUCCH format 0/1. Moreover, at least for 120 kHz SCS, the PAPR/CM performance of Alt-2 for the specific RB range (e.g., NRB around 12-16) is better than that of Alt-1. In this regard, we prefer to support Alt-2. However, if it is hard to downselect to one of Alt-1 and Alt-2, it may also be considered to configure both sequences and use one of sequence types according to the number of RB or the PUCCH resources. |
| OPPO | Support Alt-1. User multiplexing with misaligned RB allocations can be solved by sub-PRB interlaced mapping. Taking the following figure as an example, assuming the configured number of RBs is 12 and 24 for UE1 and UE2 respectively, and Alt-1 is adopted for sequence construction. Thus, user multiplexing with misaligned RB allocations can be realized by FDM multiplexing for RE interlaced mapping. |
| Nokia, NSB | We support down-selecting to one alternative, and prefer Alt-1 due to better coverage with limited number of RBs. |
| Futurewei | We prefer Alt 1. MIL is more important than UE mutliplexing.  Regarding CM, it is better to wait for the RAN4’s decision on the maximal RB to determine which of the two alternatives have better CM for the majority of RB values. |
| vivo | It seems our evaluation results/observations on the sequence Alt-1 vs. Alt-2 were not captured in the evaluation summary table above.  To summarize our evalution results, we observed MIL gain of Alt-1 over Alt-2 for single UE. When multiplexing UE is considered, Alt-1 is still better than Alt-2 for aligned RB allocation; no clear gain of Alt-2 for misaligned RB allocation for either continuous PRB or sub-PRB RE mapping. Furthermore, Alt-1 maintains better CM performance for most of RB allocation number.  On the UE multiplexing capacity, our understanding is that the maximum supported number of multiplexing users of Alt-1 is more than that of Alt-2. It is not clear to us Alt-2 has improved user multiplexing possibility vs. Alt-1 as claimed by the proponent. |

# 4 Rate matching for enhanced PF4

The following agreement was made in RAN1#104-e, and the moderator draws attention to the highlighted bullet

Agreement:

* The configured number of RBs for enhanced PF 0/1/4 is denoted NRB
  + The minimum value of NRB is 1 for PF 0/1/4 for all subcarrier spacings
  + The maximum value of NRB depends on subcarrier spacing
    - FFS: maximum value for each SCS and each of PF0/1/4
  + FFS: Allowed values of NRB within the [min/max] range
  + FFS: Details of indication of NRB by cell-specific (for PF0/1) and dedicated signaling (PF0/1/4)
  + FFS: Whether or not multiplexing of users with misaligned RB allocations is supported, where "misaligned" also includes users with different # of RBs.
  + For PF4:
    - The actual number of RBs used for a PUCCH transmission is equal to NRB, i.e., the actual number of RBs does not vary dynamically based on PUCCH payload
    - NRB fulfils the following: where is a set of non-negative integers
* Note: if frequency hopping is enabled, NRB is the number of RBs per hop

Note: decisions on the maximum value of NRB for each SCS and PUCCH format shall take into account link budgets

Given that the number of RBs does not vary dynamically based on PUCCH payload, it means that for a configured value of N\_RB, the effective code rate varies as a function of the payload.

The following table provides a summary of company proposals on this topic.

|  |  |
| --- | --- |
| **Company** | **Company Proposals** |
| Huawei | ***Proposal 5: For PUCCH format 4, the following rate matching options can be considered:***   * ***Alt-1: Rate matching to N PRBs, without changing UCI limitation*** * ***Alt-2: Copy UCI on each configured PRB and keep the legacy rate matching to 1 RB, without changing UCI limitation*** * ***Alt-3: Repeat UCI serval times and rate matching to N PRBs, without changing UCI limitation*** * ***Alt-4: Rate matching to N PRBs and remove UCI payload limitation*** |
|  |  |
|  |  |
|  |  |

This is a new topic that has not yet been discussed, and companies are invited to provide their views on this issue.

**FL Recommendation Further discuss rate matching for enhanced (multi-RB) PF4 under the constraint that the actual number of RBs does not vary dynamically based on PUCCH payload (as agreed in RAN1#104-e).**

## 4.1 <1st Round Comments>

Please provide your company view according to the above FL recommendation

|  |  |
| --- | --- |
| **Company** | **View/Position** |
| Intel | Alt-4 is preferred, but we are fine to discuss this topic further to have a better assessment of the pro and cons. |
| Nokia, NSB | Further discussion on the topic is needed, but our initial view is to prefer Alt-4. |
| Futurewei | We prefer Alt-4. Further study for detailed comparison between the alternatives is beneficial. |
| vivo | OK to FFS. |

# 5 PUCCH Resource Sets Prior to RRC Configuration

The following table provides a summary of company proposals on this topic.

|  |  |
| --- | --- |
| **Company** | **Company Proposals** |
| vivo | **Proposal 6: The indication of NRB for common PUCCH format 0/1 can be configured in the predefined table of PUCCH resource sets before dedicated PUCCH resource configuration or configured by SIB1.**  **Proposal 7: The PUCCH frequency resource and the first PRB index are dependent on the NRB.**  **Proposal 8: The sub-PRB interlace RE mapping pattern candidates should be configured by SIB1 and then dynamically indicated to UE by DCI format.**  **Proposal 11: The additional SLIV or OCC should be included in the PUCCH resource sets before dedicated PUCCH resource configuration.** |
| Intel | **Proposal 5: Enhance PUCCH resource sets before dedicated PUCCH resource configuration to support sufficient resource partitioning via either additional starting symbols or orthogonal cover codes.** |
| ZTE | **Proposal 6: The similar solution in NR-U in rel-16 can be considered for Rel-17 PUCCH enhancement before RRC connected, and the resource unit could be RBG or RB set.** |
| Lenovo/MoM | ***Proposal 5: For NR operation between 52.6 GHz and 71 GHz, if both RB configuration options including long sequence/DFT and repetition are agreed to be supported for PUCCH formats 0/1/4, number of RBs and RB configuration/mapping type needs to be added to the PUCCH* *resource sets before dedicated PUCCH resource configuration*** |
| CATT | **Proposal 6 The number of RBs for PUCCH format0/1/4 can be cell specific or UE specific RRC configured.**  **Proposal 8 The gNB needs to indicate the UE with the configured number of RBs for PUCCH format0/1/4 during the initial access process.**  Option 1: As part of table 9.2.1-1  Option 2: Directly by SIB1 |
| NTT DOCOMO | ***Proposal 5:*** *For the PUCCH resource sets before dedicated PUCCH resource configuration,* the *number of RBs for PUCCH format 0/1 can be indicated by using a PUCCH resource sets table for the 60 GHz unlicensed band operation or SIB1.*  ***Proposal 6:*** *More than one PRB should be supported even for PUCCH resource sets before dedicated PUCCH resource configuration considering the coverage during the initial access.*  ***Proposal 7:*** *At least PRB offset values in PUCCH resource sets before dedicated PUCCH resource table should be enhanced based on the number of RBs for the PUCCH resource sets.*  ***Proposal 8:*** *The potential shortage of PUCCH resource sets before dedicated should be discussed depending on the specified number of RBs for the PUCCH resource sets.* |
| Nokia | ***Proposal 4:*** *Some of the common PUCCH resource sets prior to dedicated configuration are modified with respect to RB allocation, first symbol, PRB offset, and PUCCH format 1 OCC codes, depending on the BWP SCS value.* |
| Qualcomm | **Proposal 3: RAN1 should re-design common PUCCH resource set to support both legacy and wide-band PUCCH.**  **Proposal 4: RAN1 should study how to indicate UE's capability of supporting wide-band PUCCH during initial access.** |
| LGE | **Proposal #5: A number of RBs greater than 1 should be supported even for the initial PUCCH resource and the PRB offset value also needs to be scaled by NRB**  **Proposal #6: To determine the value of NRB for the initial PUCCH resource, the following options can be considered:**   * **Opt.1: Directly use the predefined maximum value of NRB for PF 0/1 in the specification.** * **Opt.2: Use the value of NRB configured through RRC signalling (e.g., SIB1) by gNB.** * **Opt.3: Calculate the value of NRB based on the size of the initial BWP and the required number of FDM resources for each PUCCH resource set.**   **Proposal #7: To address the potential shortage of PUCCH resources for the initial PUCCH resource set resulting from using multi-PRB to transmit PUCCH formats 0 and 1, consider the following alternatives:**   * **Alt. 1: Use only valid resources in the frequency domain** * **Alt. 2: Support additional starting symbol and OCC index**   **Proposal #8: Considering the available number of RBs in the initial BWP and more than 1 RB allocated for an initial PUCCH resource, discuss how to configure the hopping distance to obtain hopping gain equally for each initial PUCCH resource.** |
| Huawei | ***Proposal 4: The enhanced PUCCH formats 0/1 are applicable both with common and dedicated PUCCH resource. The enhanced PUCCH format 4 is applicable only with dedicated PUCCH resource.*** |
| Apple | ***Proposal 6:*** *For PUCCH Resource Sets prior to RRC configuration the UE should use the value of NRB configured through SIB1.* |
| Ericsson | **Proposal 5 For PUCCH resource sets prior to RRC configuration, support 120 kHz SCS only**  **Proposal 6 For PUCCH resource sets prior to RRC configuration, support indication via SIB1 of the number of RBs, NRB, for PUCCH format 0/1. If the number of RBs is not indicated, the UE assumes single RB. FFS: supported value(s) of NRB.**  **Proposal 7 For PUCCH resource sets prior to RRC configuration, RAN1 should discuss whether or not to design the hopping pattern for multi-RB PF0/1 so as to equalize the hopping distance (and thus frequency diversity) amongst all PUCCH resources within a set. The discussion should considering whether or not potential resource fragmentation is an issue.**  **Proposal 8 Assuming that the number of RBs is configurable in SIB1, RAN1 should use the Rel-15 PUCCH configuration table 9.2.1-1 as a starting point for discussion on configuration of PUCCH resource sets prior to RRC configuration in combination with an updated procedure on the starting RB indices of the multi-RB PUCCH resources in a set. It can be further discussed whether/how to enable additional PUCCH resources on top, with the constraint of no more than 16 per set.** |

Several issues have been raised in company contributions:

* Number of RBs
  + Some companies propose to support configuration of the number of RBs via SIB1
  + Other companies propose hardwiring the number of RBs in the table used to configure PUCCH resource sets prior to RRC configuration (see Rel-15/16 table in 38.213 Section 9.2.1 copied here for convenience):

**Table 9.2.1-1: PUCCH resource sets before dedicated PUCCH resource configuration**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Index** | **PUCCH format** | **First symbol** | **Number of symbols** | **PRB offset** | **Set of initial CS indexes** |
| 0 | 0 | 12 | 2 | 0 | {0, 3} |
| 1 | 0 | 12 | 2 | 0 | {0, 4, 8} |
| 2 | 0 | 12 | 2 | 3 | {0, 4, 8} |
| 3 | 1 | 10 | 4 | 0 | {0, 6} |
| 4 | 1 | 10 | 4 | 0 | {0, 3, 6, 9} |
| 5 | 1 | 10 | 4 | 2 | {0, 3, 6, 9} |
| 6 | 1 | 10 | 4 | 4 | {0, 3, 6, 9} |
| 7 | 1 | 4 | 10 | 0 | {0, 6} |
| 8 | 1 | 4 | 10 | 0 | {0, 3, 6, 9} |
| 9 | 1 | 4 | 10 | 2 | {0, 3, 6, 9} |
| 10 | 1 | 4 | 10 | 4 | {0, 3, 6, 9} |
| 11 | 1 | 0 | 14 | 0 | {0, 6} |
| 12 | 1 | 0 | 14 | 0 | {0, 3, 6, 9} |
| 13 | 1 | 0 | 14 | 2 | {0, 3, 6, 9} |
| 14 | 1 | 0 | 14 | 4 | {0, 3, 6, 9} |
| 15 | 1 | 0 | 14 |  | {0, 3, 6, 9} |

* Subcarrier spacing
  + It is not clear from all contributions what SCS(s) companies have in mind for PUCCH resource sets prior to RRC configuration. It is the moderator's understanding that these PUCCH resources are used only during initial access, e.g., for HARQ ACK of Msg4. Hence, the subcarrier spacing is the one configured for the initial UL BWP by SIB1.
  + It seems there is a dependency on the initial access agenda item to have clarification on which SCS(s) are supported for the initial UL BWP
* RB indexing
  + Several companies observe that updates to the formulas in 38.213 Section 9.2.1 for the RB index of the first and second hop need to be updated to account for PUCCH resources with multiple RBs
  + It would make sense to define the lowest PRB index of a PUCCH resource such that this index along with the configured/specified value of N\_RB is sufficient for defining the PUCCH resource location within the BWP
* Frequency hopping distance
  + For Rel-15/16, the formulas in 38.213 Section 9.2.1 for the RB indexes of the first and 2nd hop do not attempt to equalize the hopping distance for all 16 PUCCH resources in a set since a PUCCH resource consists of only a single RB per hop, and the PUCCH resource in each hop is located close to the edge of the BWP. For a large enough initial UL BWP, the achieved frequency diversity is roughly similar for all resources in the set.
  + For enhanced (multi-RB) PUCCH depending on the BWP size and N\_RB, it can happen that the hopping distance can be quite small for some resources in the set. The question is should the hopping formulas be adjusted to achieve equal hopping distance for all resources in a set?
    - The following diagram from [6] illustrates an example when the hopping distance is equalized for all resources (using row 4 from Table 9.2.1 as an example). For non-equalized hopping distance, the same diagram applies, except for the 2nd hop, the red/green colors should be swapped and the blue/yellow colors should be swapped.



Figure 9: Example PUCCH resource configuration corresponding to row 4 of Table 9.2.1-1 extended to support enhanced (multi-RB) PUCCH Format 0/1, i.e., NRB > 1. Equal hopping distance for all resources is assumed.

* Shortage of RBs
  + Depending on the size of the initial UL BWP, the number of RBs of a PUCCH resource (N\_RB), and the parameters in a given row of Table 9.2.1 (particularly the PRB offset) it can happen that there is a shortage of RBs that complicates defining 16 PUCCH resources in a set
  + Several companies have suggested solutions for this problem, e.g.,
    - Allow gNB to configure an appropriate value of N\_RB to ensure there is no shortage for the desired row index.
    - UE calculates N\_RB based on the size of the initial BWP and the required number of FDM resources for each PUCCH resource set (row of the configuration table) to ensure there is no shortage
    - Specify additional OCCs and/or SLIVs for some rows of the table to allow a full set of 16 resources to be constructed
    - Disallow large PRB offsets in the table when multiple RBs are configured
    - Restrict allowed values of the PUCCH resource index r\_PUCCH so that for some rows of the configuration table a full set of 16 resources is not constructed
    - Combination of the above

Since this is a new topic, a number of questions are posed in the following sub-sections to try to structure the discussion.

## 5.1 Indication of Number of RBs

The indication of the number of RBs for PUCCH resource sets prior to RRC configuration is the first decision that should be made, since it will unlock progress on the overall design.

### 5.1.1 <1st Round Comments>

**Question**: How should the number of RBs be configured for PUCCH resource sets prior to RRC configuration, e.g.,

* **Alt-1**: Via a new parameter in SIB1
* **Alt-2**: Hardwired by specification
  + Alt-2a: Single value applicable to all rows of PUCCH configuration table
  + Alt-2b: Different value depending on row of the PUCCH configuration table
* **Alt-3**: Calculated by UE and gNB based on size of initial BWP and required number of RBs for a given row of the PUCCH resource set configuration table

|  |  |
| --- | --- |
| **Company** | **View/Position** |
| Moderator view | Alt-1 for most flexibility considering differing requirements for N\_RB in various regulatory regions and deployment scenarios. If parameter is not configured, the UE assumes N\_RB = 1 (legacy PUCCH). |
| Intel | We share same view as the feature lead, and we prefer Alt-1. |
| LG | We prefer Alt-1 and Alt-3, but we are fine to further discuss this topic considering all alternatives. |
| OPPO | Support Alt-2. |
| Nokia, NSB | Support Alt-2b. We see that it can provide sufficient flexibility and there is no need to introduce new SIB1 parameter. |
| Futurewei | Support Alt-1 that SIB1 is used to configure the number of RBs for PUCCH prior to RRC. The PUCCH configuration table may need non-trivial modification effort to accomodate the multi-RB configuration. |
| vivo | Our slight preference is Alt-1 and Alt-2b. |

## 5.2 Subcarrier Spacing

### 5.2.1 <1st Round Comments>

**Question**: What is your view on the SCS(s) supported for PUCCH resource sets prior to RRC configuration, i.e., during initial access?

|  |  |
| --- | --- |
| **Company** | **View/Position** |
| Modertor view | There is a dependency on decisions in the initial access agenda item. |
| Intel | We share the same view as the moderator and perhaps this could be postponed at a later time. |
| LG | Base on the agreements so far, only 120 kHz SCS is supported for the initial access. |
| OPPO | This can be discussed later when initial access discusison outcome beomes clear. |
| Nokia, NSB | We see also the dependency on the decisions made for initial access and that this topic can progress only after the relevant decisions on initial access subcarrier spacing(s) have been reached. |
| Futurewei | Agree that there is a dependency on decisions in the initial access agenda item regarding this question. |

## 5.3 Frequency Hopping Distance

### 5.3.1 <1st Round Comments>

**Question**: What is your view on the frequency hopping distance (in RBs) between the 1st and 2nd hop of PUCCH resources within a PUCCH resource set?

* **Alt-1**: Hopping distance should be the same for all PUCCH resources within a PUCCH resourse set
* **Alt-2**: Hopping distance can be different for the different resources in a PUCCH resource set.

|  |  |
| --- | --- |
| **Company** | **View/Position** |
| Moderator view | Alt-1 to enable equal frequency diversity (coverage) for all PUCCH resources within a set. |
| Intel | Alt-2 is supported. Given the number of PRBs for initial UL BWP is relatively large, performance difference between Alt-1 and Alt-2 may be minor. However, the spec impact on Alt-2 is smaller if mirrored pattern is agreed similar to Rel-15. |
| LG | We support Alt-1.  Considering the available number of RBs in the initial BWP and the multi-RB is used to transmit the initial PUCCH resource, the diversity gain of frequency hopping may not be enough. Therefore, it is necessary to discuss how to configure the hopping distance to obtain hopping gain equally for each PUCCH resource. |
| OPPO | This issue can be resolved nicely with sub-PRB mapping. Thus, we should not presume that full-PRB is adopted and intentionally create this issue. |
| Nokia, NSB | It may be necessary to agree on the number of supported PRBs first, before concluding this topic. We see that Alt-1 can be considered when the number RBs in the common PUCCH resource set is large enough to have considerable impact on the hopping distance. Otherwise Alt-2 can be continued to be used. |
| Futurewei | Share the view with Nokia that if the number of RBs is large enough, Alt-1 is considered, otherwise Alt-2. |
| vivo | As commented by other companies, we think this issue is related to the discussion on the maximum number of RB and RE mapping. So we suggest to postpone the discussion on this matter. |

## 5.4 Handling Potential RB Shortage

### 5.4.1 <1st Round Comments>

**Question**: What is your view on how a potential shortage of RBs should be handled based on a given size of the UL BWP, given configured/specified value of N\_RB, and given row index in the configuration table? Some examples provided by company contributions are the following:

* **Alt-1**: Allow gNB to configure an appropriate value of N\_RB to ensure there is no shortage for the desired row index
  + This is related to Alt-1 in Section 5.1
* **Alt-2**: Hardwired value(s) in specification ensure there is no shortage
  + This is related to Alt-2 in Section 5.1
* **Alt-3**: UE calculates N\_RB based on the size of the initial BWP and the required number of FDM resources for each PUCCH resource set (row of the configuration table) to ensure there is no shortage
  + This is related to Alt-3 in Section 5.1
* **Alt-4**: Specify additional OCCs and/or SLIVs for some rows of the table to allow a full set of 16 resources to be constructed
* **Alt-5**: Disallow large PRB offsets in the table when multiple RBs are configured
* **Alt-6**: Restrict allowed values of the PUCCH resource index r\_PUCCH so that for some rows of the configuration table a full set of 16 resources is not constructed
* Combination of the above alternatives
* Other alternatives?

|  |  |
| --- | --- |
| **Company** | **View/Position** |
| Moderator view | Support at least Alt-1  Further discuss whether/how to support Alt-4 in addition to Alt-1 to allow large N\_RB while still supporting 16 resources in a PUCCH resource set. Alt-4 may not be needed for all rows. |
| Intel | We share same view as the moderator, and we support at least Alt-1, and Alt-4 should be considered for those resources sets for which frequency partitioning is not possible. |
| LG | We support Alt-3 and Alt-4. Smilar to NR-U, the additional CDMed or TDMed PUCCH resources can be provided until 16 PUCCH resources can be available. For example, a method of applying additional starting symbol index or OCC index based on the value of (pre-defined or configured) NRB can be considered. Another way is that the value of NRB for initial PUCCH resource can be determined considering the available number of RB in the initial bandwidth part and the required number of FDM resources for each PUCCH resource set. |
| OPPO | RB shortage issue can be nicely resolved by sub-PRB mapping. Thus, we should not presume that full-PRB is adopted and intentionally create this issue. |
| Nokia, NSB | Support at least Alt-4 and, depending on related number of RBs, Alt-5. We see that this discussion heavily depends on the supported maximum number of RBs as well as on the SCS values supported for initial access and, hence, benefits from waiting for decisions on these topics. |
| Futurewei | Support at least Alt-1. While Alt-5 seems also a convenient solution. |
| vivo | Since this issue is related to indication of RB numbers, suggest to wait for the outcome of that discussion before this one. |

# References

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6. R1-2104461 PUCCH enhancements Ericsson
7. R1-2104508 Enhancements for PUCCH formats for up to 71GHz operation CATT
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21. R1-2105929 Enhancement on PUCCH formats Huawei, HiSilicon