3GPP TSG-RAN WG1 Meeting #104-e R1-2101794

e-Meeting, 25th January – 5th February, 2021

Agenda Item: 8.2.3

Source: Moderator (Ericsson)

Title: FL Summary for Enhancements for PUCCH formats 0/1/4

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 is an outline of the summary. An asterisk (\*) indicates that a proposal/discussion is to be treated with higher priority.

2 Link level evaluation assumptions for design of PUCCH Format 0/1/4 enhancements \*FL Proposal

3 Frequency Domain Resource Mapping

3.1 Contiguous vs. Interlaced Mapping \*FL Proposal

3.2 Number of RBs FL Proposal

4 PUCCH Format 0/1 Sequence Type \*FL Proposal

5 PUCCH Format 4

5.1 Sequence Type for DMRS \*FL Proposal

5.2 DFT Precoding and OCC Mapping FL Proposal

6 PUCCH Resource Sets Prior to RRC Configuration Defer discussion

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

[104-e-NR-52-71GHz-03] Email discussion/approval on PUCCH format 0/1/4 enhancements with checkpoints for agreements on Jan-28, Feb-02, Feb-05 – Steve (Ericsson)

# 2 Link level evaluation assumptions for design of PUCCH Format 0/1/4 enhancements

As many companies have discussed in their contributions, one of the main issues is to determine the number of RBs to specify for enhanced PUCCH formats 0/1/4 in order to enable increased coverage under various power limitations. In order to make decisions on the number of supported RBs, link budget calculations are required taking into account regional regulatory and practical UE limitations on conducted power, beamforming gain, and PSD. In turn this depends on the PUCCH detection performance evaluated by link level simulation. To align evaluation results between companies, it will be very useful to agree on a common set of link level evaluation asumptions. The same exercise was done in Rel-16 in the NR-U work item for design of interlaced PUCCH [3]. Tables 1, 2, and 3 below provide a proposal for discussion.

* Table 1 provides a set of link level simulation settings to be used for determining the required SNR to achieve a PUCCH detection error reqirement. This table is a simplified version of the link level evaluation assumptions from TR 38.808 [2] that were agreed during the study item, adapted for PUCCH evaluation. The required SNR from link level simulations is one of the inputs to the link budget calculation shown in Table 2.
* Table 2 is substantially similar to the table agreed in [3] for the Rel-16 PUCCH evaluations, with small adaptations to align with the scope of the WID for the 52.6 – 71 GHz WI. This table lists metrics to be reported by companies in future contributions during this WI, and includes expressions to derive the link budget in terms of maximum isotropic loss (MIL)
* Table 3 provides expressions for computing the maximum conducted power according to regional regulatory limitations. The maximum conducted power is another one of the inputs to the link budget calculation shown in Table 2.

1. Agree to the following

Agree on a common set of assumptions contained in Tables 1, 2, and 3 for link level simulations and link budget calculations for evaluating enhancements to PUCCH formats 0/1/4.

Table 1: Simplified Evaluation Assumptions

| Assumptions | Value |
| --- | --- |
| Carrier Frequency [GHz] | 60 GHz |
| Subcarrier Spacing [kHz] | 120, 480, 960 kHz |
| Number of usable RBs per carrier | 256 for 120 kHz SCS (corresponds to ~400 MHz carrier)  256 for 480 kHz SCS (corresponds to ~1600 MHz carrier)  160 for 960 kHz SCS (corresponds to ~2000 MHz carrier)    Note: If other values used, companies to report values |
| PUCCH Frequency Hopping | On |
| PUCCH Frequency Domain Resource Mapping | N\_RB contiguous RBs per hop (with all REs allocated per PRB)  Note: If alternative RE allocation per PRB is used, companies to report details |
| Waveform | CP-OFDM for PF0/1  DFT-s-OFDM for PF4 |
| CP Type | Normal CP |
| Channel Model | TDL-A model as defined in of TR38.901 Section 7.7.2:  - Delay spread (DS) = {5ns, 10ns, 20ns}  - Optional: DS = 40ns |
| BS Antenna Configuration (Mg,Ng,M,N,P) | {1,1,1,1,2} |
| UE Antenna Configuration (Mg,Ng,M,N,P) | {1,1,1,1,1} |
| Mobility | 3 km/hr |
| PA Model | None |
| gNB TRP PN Model | Zero phase noise |
| UE PN Model | Zero phase noise |
| Pre-loaded Tx EVM | 0% |
| Additive Rx EVM | 0% |
| I-Q Imbalance | None |
| Frequency Offset | 0 ppm |
| Channel Estimation | Realistic channel estimation |

Table 2: Reporting metrics

|  |  |  |
| --- | --- | --- |
| **Parameter** | **Value** | **Notes** |
| PUCCH Format |  | PF0, PF1, PF4 |
| Subcarrier spacing, SCS [kHz] |  | SCS = {120, 480, 960} kHz |
| Number of RBs used per hop (N\_RB) |  | N\_RB contiguous RBs per hop |
| PUCCH bandwidth per hop, BW [MHz] |  | BW = N\_RB \* 12 \* SCS / 1e6 |
| Number of OFDM symbols used for PUCCH resource |  | 1 or 2 for PF0/1  {4 .. 14} for PF4 |
| Sequence construction details |  | Sequence type for PF0/1  Sequence type for DMRS of PF4 |
| OCC configuration details |  | Applicable for PF1, PF4 |
| Cyclic shift configuration details |  | For PF0/1  For DMRS of PF4 |
| Number of multiplexed users, e.g., by code division, if applicable |  | 1 user  Note: Companies to report if other cases if evaluated |
| PUCCH payload encoder type |  | Reed Muller or Polar for PF4 |
| PUCCH payload size(s) (bits) |  | If multiple payload sizes evaluated, then maximum isotropic loss (see calculation below) to be reported for each PUCCH payload size |
| PUCCH encoding rate(s) |  | Applicable for PF4  If multiple payload sizes evaluated, encoding rates to be reported for each payload size |
| Required SNR (dB) |  | Required SNR needed to fulfil detection criterion, from link level simulations based on Table 1 (see Notes (1) and (2) at bottom of table for definition of detection criteria for PF 0/1/4). |
| Cubic Metric, CM (dB) |  | Reported value is the 95th percentile, i.e., the CM for which 95% of all sequences of the design fall below |
| UE Tx Beamforming gain (dBi) |  | TxBF = 6 dBi  Notes:   1. TxBF includes antenna element gain 2. If other TxBF value(s) used, companies to report value(s) |
| BS Rx Beamforming gain (dBi) |  | RxBF = 20 dBi  Notes:   1. RxBF includes antenna element gain 2. If other RxBF value(s) used, companies to report value(s) |
| UE Power Limitations |  | Maximum EIRP:  UE\_EIRP = 25 dBm  Maximum conduced power (prior to consideration of backoff):  UE\_P = 21 dBm    Optional:  - UE\_EIRP = 40dBm  - UE\_P = 21 dBm  Note: Companies to report if other cases evaluated |
| Pmax (dBm) |  | Maximum allowed conducted power considering combined limit per region (from Table 3).  Note:Companies should report if Pmax is considered per region or a combined limit is considered across multiple regions |
| Backoff (dB) |  | Power backoff is equal to the cubic metric, CM  Note: If cubic metric is not used, information on the backoff metric used should be provided. |
| Transmit power, P\_TX (dBm) |  | Maximum allowed transmit power including UE power limitation and backoff  P\_TX = min(Pmax, UE\_EIRP – TxBF, UE\_P – Backoff) |
| Noise power, P\_N (dBm) |  | BS Noise Figure, NF = 7 dB  Noise PSD = -174 dBm/Hz  P\_N = Noise PSD + 10\*log10(BW \* 1e6) + NF  Note: BW is the PUCCH bandwidth per hop in MHz |
| Maximum Isotropic Loss, MIL (dB) |  | MIL = P\_TX – P\_N – Required SNR + TxBF + RxBF |
| Definition of detection criteria for PF0/1/4:  (1) For PF0/1 (payload of 1 or 2 bits) the detection criterion assumes that the PUCCH payload consists of randomly drawn HARQ ACK/NACK bits and the criterion is defined as the SNR for which P(ACK to Error) ≤ 1% AND P(NACK to ACK) ≤ 0.1%. Error is defined as NACK or DTX where the decision region for DTX is determined to ensure that the maximum P(DTX to ACK) ≤ 1% for the case when the input to the receiver is noise only.  (2) For PF4 (payload greater than 2 bits): the detection criterion is the UCI block error probability BLER ≤ 1% (as in TS38.104 Section 8.3.6) | | |

Table 3: Regulatory Power Limits by Region

|  |  |
| --- | --- |
| **Region** | **Maximum Conducted Power, Pmax (dBm)** |
| US | Conducted power limit due to EIRP limit:  Pmax\_EIRP = 40 dBm - TxBF  Conducted power limit as a function of PUCCH BW per hop:  Pmax\_P = 27 dBm – max(0, 10\*log10(100 / BW))  Combined limit:  Pmax = min(Pmax\_P, Pmax\_EIRP) |
| Europe | Conducted power limit due to EIRP limit:  Pmax\_EIRP = 40 dBm – TxBF  Conducted power limit due to PSD limit (assumes N\_RB contiguous RBs with all REs allocated per PRB):  Pmax\_PSD = 23 dBm/MHz + max(0, 10\*log10(BW)) - TxBF  Combined limit:  Pmax = min(Pmax\_PSD, Pmax\_EIRP) |
| South Korea | Conducted power limit due to EIRP limit:  Pmax\_EIRP = 43 dBm – TxBF when an equipment is >=300m from an astronomical antenna  Pmax\_EIRP = 43 dBm – TxBF when an equipment is <300m from an astronomical antenna  Conducted power limit due to PSD limit (assumes N\_RB contiguous RBs with all REs allocated per PRB):  Pmax\_PSD = 13 dBm/MHz + max(0, 10\*log10(BW)) - TxBF  Combined limit:  Pmax = min(Pmax\_PSD, Pmax\_EIRP) |
| Other regions | … |
| Note: BW is the PUCCH bandwidth per hop in MHz | |

## 2.1 <1st Round Comments>

Please provide your company view on the above proposal on assumptions for for link level simulations and and link budget computation.

|  |  |
| --- | --- |
| **Company** | **View/Position** |
| Qualcomm | Agree with the proposal |
| Intel | We are generally OK with the simulation assumptions. However, we recommend to capture in Table 3 also the current regulatory requirements of South Korea, which has a PSD restriction of 13 dBm/MHz and allow a maximum EIRP of 43 dBm if 300m or further from an astronomical antenna, or 27 dBm otherwise. Please note, that we have added the above restriction in Red in Table 3. |
| Apple | We agree with the proposal. We would like to add the following:   * Baseline frequency hopping should be intra-slot FH if simulated * Would be good to have 1 payload size value for PF4 e.g. 11 bits (RM) and 1 payload size for polar (e.g. 22 bits) |
| vivo | Table 1, frequency hopping is on. Need details on how the hopping is performed. E.g., what’s the assumption on the number of RB offset between two hops.  Table 2, only evaluate 1 or 2 OFDM symbols for PUCCH format 1? |
| Futurewei | We agree with the proposal |
| InterDigital | We are fine with the proposal. |
| Samsung | We’re fine with the propsal. |

# 3 Frequency Domain Resource Mapping

## 3.1 Contiguous vs. Interlaced Mapping

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

|  |  |
| --- | --- |
| **Company** | **Company Proposals** |
| vivo | Proposal 2: Support multi-sub-PRB based PUCCH format 0/1 for power boosting and coverage enhancement for NR operation from 52.6-71GHz.  Proposal 3: The RE and sequence mapping pattern of multi-sub-PRB based PUCCH needs further study.  **Proposal 4: For PUCCH format 4, multi-PRB or multi-sub-PRB based PUCCH need further evaluation as well as the RE and sequence mapping pattern.** |
| Qualcomm | **Proposal 1: NR should support configuring contiguous RB assignment for PUCCH format 0/1 in 60GHz unlicensed band.** |
| Nokia | ***Proposal 1:*** *Support contiguous multi-RB allocation for PUCCH formats 0, 1 and 4.* |
| Samsung | **Proposal 1: Enhanced PUCCH format 0/1/4 should be based on contiguous multi-PRB allocation.** |
| WILUS | * *Proposal 1: The interlaced design for PUCCH format 0/1/4 seems not necessary to apply to 60GHz unlicensed spectrum from the perspective of power boosting.* |
| NTT DOCOMO | ***Proposal 1****: At least the following aspects should be discussed to increase the number of RBs for PUCCH format 0/1/4.*   * *The number of allocated RBs* * *Resource allocation methods* * *Mapping to physical resources operation* |
| MediaTek | **Proposal 1: PRB and sub-PRB interlace are not supported for PUCCH format 0/1/4 in 60 GHz band.** |
| Spreadtrum | ***Proposal 1: Support contiguous multi-PRB allocation of PUCCH format 0 and format 1 to achieve higher transmit power when PSD limits apply.*** |
| OPPO | **Proposal 1: adopt interlace structure for PUCCH format 0, 1 and 4 with 120kHz subcarrier spacing.**  **Proposal 2: adopt sub-PRB allocation for PUCCH format 0, 1, 4 for 120kHz.** |

At least for 480/960 kHz SCS, many companies observe that a single PRB spans more than the 1 MHz measurement bandwidth defined in PSD regulations such that there is no possibility for power boosting by using PRB-based interlaced mapping. Seveeral companies also observe that for 480/960 kHz, sub-PRB interlacing is not beneficial either, since a sub-PRB unit (e.g., 2 REs) is equal to or exceeds the 1 MHz measurement bandwidth.

For 120 kHz SCS, some companies observe that sub-PRB interlacing can provide a power boosting gain; however, some other companies are concerned with the specification impact. For companies proposing sub-PRB interlacing, it is assumed that a subset of REs within each RB are allocated for PUCCH; however, the PRBs in which PUCCH is mapped are still contiguous.

Based on company contributions, it seems at least the following is agreeable.

1. Agree to the following

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

* 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)

### 3.1.1 <1st Round Comments>

Please provide your company view on the above proposal

|  |  |
| --- | --- |
| **Company** | **View/Position** |
| Moderator | **Question**:  In Alt-2, sub-PRB allocation for PF0/1 will mean that cyclic shifts are no loner orthogonal within each PRB (as in Rel-15/16). What impact does this have on performance in a dispersive channel? |
| Qualcomm | Support the proposal. A unified design is preferred across different SCSs. Thus, we believe that contiguous RB and FULL RE be mapped can be adopted for 120/480/960KHz SCS, i.e., support Alt-1. Sub-PRB in Alt-2 complicates the design and the additional power boosting possible can be achieved by allocating more RBs for Alt-1. |
| OPPO | proposal 2 looks fine to us.. |
| Intel | We are Ok with proposal 2. As for 120 KHz SCS, our preference is Alt-1, and we share same concerns as the moderator regarding the penalties that Alt.2 would incur especially in a frequency dispersive channel. As for the FFS, we feel this is redundant with proposal 3, and it is not needed. |
| Apple | For 120 kHz, we support Alt-1 so that we have a general design across all SCSs and to reduce the specification load if Alt-2 is specified. |
| vivo | We suggest to remove “per hop” in the main bulle to avoid misinterpretation that continuous allocation of RBs only when frequency hopping is on.  Given proposal 1 in section 2 is to agree LLS assumptions for evaluations, we feel it’s premature to conclude only Alt-1 is supported for 120 kHz SCS for now.  Respond to Moderator’s question, the perforamnce impact of sub-PRB allocation for PF0/1 will be evaluated once we have the agreed LLS assumptions. |
| Futurewei | For 120 kHz we prefer Alt-1. We are OK with the first two bullets. |
| MediaTek | Support this proposal with Alt-1. |
| InterDigital | We think that Alt-2 complicates the design without clear benefits. So, we suggest to remove Alt-2 and focus only Alt-1. |
| Samsung | Agree with proposal 2, and we support Alt-1 for 120KHz SCS.  For 120KHz SC Alt-2, similar discussion for sub-PRB interlaced mapping happend in Rel-16 NR-U without support, and we fail to see the new motivation to discuss it again here. |

## 3.2 Number of RBs

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

|  |  |
| --- | --- |
| **Company** | **Company Proposals** |
| Intel | **Proposal 1: The transmission of PUCCH format 0 and 1 spans across a number of contiguous PRBs, which is configured by higher layer signaling.**  **Proposal 3: The transmission of PUCCH format 4 spans across a number of contiguous PRBs, which is configured by higher layer signaling** |
| Ericsson | **Proposal 1** RAN1 should discuss and decide the number of RBs to support for Rel-17 PUCCH enhancements for each of the supported subcarrier spacings separately. The number of RBs should depend on regulatory power limits, practical UE power limitations, and practical Tx beamforming gains. |
| Futurewei | [**Proposal 1** **To** **increase the spectrum utilization, especially**](#_Toc53775918) **for high-power equipment, multiple RBs should be used for PF0/1/4. Longer sequence or repetition in frequency-domain should be considered.**  [Proposal 2 Evaluate](#_Toc53775918) the coverage gain for PF0 by allowing multiple RBs and calculate to determine if the intended coverage range can be maintained. |
| Lenovo, MoM | ***Proposal 1: For NR operation between 52.6 GHz and 71 GHz, increased RB allocation for PUCCH formats 0/1/4 should be supported*** |
| Qualcomm | **Proposal 3: NR should support PUCCH format 0/1 with different bandwidth for different UEs simultaneously.** |
| Huawei | ***Proposal 1: For operation in shared spectrum from 52.6GHz to 71GHz, Rel-15 PUCCH formats 0/1/4 can be used for 120 kHz and can be extended to 480 kHz and 960 kHz SCS.***  ***Proposal 2: For enhanced PUCCH formats 0/1/4 in the shared spectrum from 52.6GHz to 71GHz，the maximum transmission bandwidth is 50 MHz.*** |
| LGE | **Proposal #1: The minimum required number of RBs to increase transmit power for PUCCH format 0/1/4 can be predefined (based on the regulatory requirements) or configured/indicated by gNB for each subcarrier spacing.** |
| Nokia | ***Proposal 1:*** *Support contiguous multi-RB allocation for PUCCH formats 0, 1 and 4.*  The number of RBs that are needed for the enhanced PUCCH depend on a number of factors:   * PSD limit applied on the region. * Subcarrier spacing. When PSD limit constrains the transmitted EIRP, there can be up to 9 dB EIRP difference between 120 kHz and 960 kHz SCSs. * Targeted EIRP. This depends e.g. on expected pathloss, UCI payload size (with PUCCH format 4), and UE power class (in case of dedicated resources). |
| Samsung | **Proposal 4: Support multi-PRB PUCCH format 4 by reusing PUCCH format 3 with minor modification:**   * **Pre-DFT OCC across contiguous multiple PRBs for UCI** * **FFS using single long sequence over multiple PRBs or single-PRB sequence repetition over multiple PRBs for DMRS, depending on whether support multiplexing between UEs with non-aligned PRBs.** * **Do not support PRB scaling according to UCI payload and configured coding rate.** |
| CATT | **Proposal 1** The PSD limit and the supported EIPR value should be discussed in details before deciding the number of required RBs for different SCS for PUCCH format0/1. |
| Apple | ***Proposal 1:*** *At least for PUCCH FM0, FM1 and FM4, N consecutive RBs are allocated for PUCCH.*   * *N should be based on the SCS, waveform restrictions for each format and the UE power class.* * *N can be configured by the gNB* |
| NTT DOCOMO | ***Proposal 2****: Enhancements for PUCCH format 4 may not be necessary and enhancements for PUCCH format 0/1 can be prioritized depending on the enhancement workload.* |

Many companies have observed that regional regulatory limitations and practical UE limitations on conduced power, PSD, and EIRP shall be considered when determining the number of PRBs supported for PUCCH Formats 0/1/4. The number of supported PRBs depends on the subcarrier spacing due to the fact that some regulatory limitations depend on the the PUCCH bandwidth. It also depends on the assumed UE Tx beamforming gain, since the conducted power plus Tx beamforming gain determine now many RBs are needed to reach the various EIRP limits.

The open issue to discuss is the minimum and maximum number of RBs supported for each SCS (120, 480, 960 kHz) and the degreed of configurability within the [min,max] range considering the regulatory and practical UE limitations as well as the detection performance for a given PUCCH design. The detection error performance is one of the inputs to link budget calculations, and in Section 2 of this summary, a common set of evaluation assumptions for link simulation and link budget computations is proposed.

Another open issue do discuss is raised in [17], and that is with respect to PUCCH Format 4. For PF4, the issue is whether or not the # of PRBs used for a PF4 PUCCH transmission should depend on the actual PUCCH payload (like for PF3 in Rel-15) in which case the number of PRBs could be less than the RRC configured value. The alternative would be that the number of PRBs for a PF4 transmission is fixed (like for interlaced PF3 in Rel-16 where it is fixed to 10 PRBs).

1. The following is proposed for discussion

Further discuss at least the following aspects regarding the number of PRBs for enhanced (multi-RB) PF 0/1/4:

* Minimum and maximum [min/max] configured number of PRBs for each PUCCH format for each SCS 120, 480, and 960 kHz
  + For PF4, it is assumed that the number of RBs fulfils where is a set of non-negative integers
* Granularity of configuration, i.e., supported number of values within [min/max] range
* Whether or not actual number of PRBs for a PF4 transmission depends on the PUCCH payload, or if it is fixed at the RRC configured value

Note: The discussion should take into account link budgets for various practical UE and regional regulatory power limitations including detection performance for considered PUCCH design candidates and UE Tx beamforming gain.

### 3.2.1 <1st Round Comments>

Please provide your company view on the above discussion points. Realistically, it will not be possible to nail down precise values in this meeting, since further evauation using a common set of assumptions (as proposed in Section 2) is required.

|  |  |
| --- | --- |
| **Company** | **View/Position** |
| Qualcomm | For PF0/1, gNB configure the number of RB based on EIRP and channel condition. The minimum RB should be 1 (legacy). To simplify design, possible to define a few values for gNB to choose from, such as 1, 2, 4, 8, 12, …  For PF4, can borrow PF3 design with a variable # of RBs, with a minimum value configured |
| OPPO | Since the enhancement is motivated by PSD limitation, we think the PUCCH bandwidth achieving max EIRP should be the baseline, e.g. 32 PRB for 120kHz, 8 PRB for 480kHz, and 4 PRB for 960kHz. |
| Intel | We are generally OK with the proposal. However the text could be further improved as follows:  Further discuss at least the following aspects regarding the number of PRBs for enhanced (multi-RB) PF 0/1/4:   * Minimum and maximum [min/max] configured number of PRBs for each PUCCH format and for each supported SCS ~~[20, 480, and 960] kHz~~   + ~~F~~or PF4, it is assumed that the number of RBs fulfils where is a set of non-negative integers * Granularity of configuration, i.e., supported number of values within [min/max] range * Whether or not actual number of PRBs for a PF4 transmission depends on the PUCCH payload, or if it is fixed at the RRC configured value   Note: The discussion should take into account link budgets for various practical UE and regional regulatory power limitations including detection performance for considered PUCCH design candidates and UE Tx beamforming gain.  The changes made above are motifated by the fact that it is not needed to list all SCS, but it could be sufficient to indicate that we would need to identify the maximum ad minimum number of PRBs for each of the supported SCS, since the downselection is still ongoing in other agenda items. |
| Apple | * This may be a typo: it is assumed that the number of RBs fulfils where is a set of non-negative integers. Assume that we need this restriction due to the DFT-S-OFDM restrictions. * As observed, N will depend on multiple outside factors/parameters. RAN1 should agree on some values for the parameters/factors to be able to dimension the range of N needed and the associated granularity. The minimum will depend not only on the regulatory limits but on the UE power class and as such, could be 1 if the right conditions arise. * The actual number of PRBs for a PF4 transmission is fixed at the RRC configured value. If we go with a UE autonomous value, this may increase the specification effort to make sure that both gNB and UE have a common understanding and to make sure that the maximum transmit power is used. |
| vivo | In principle, we are okay with this proposal.  However, like to understand the intention of the sub-bullet of the 1st bullet, “For PF4, it is assumed that the number of RBs fulfils N\_RB=2^(α\_2 )∙2^(α\_3 )∙2^(α\_5 ) where α\_2,α\_3,α\_5 is a set of non-negative integers“. |
| Futurewei | We would prefer that the PUCCH bandwidth that achieves maximum allowed power (EIRP) to be the baseline. The minimum may be the 1. The granularity can be further discussed. |
| InterDigital | We are fine with the proposal. |
| Samsung | We are generally OK with the proposal. We also agree with Apple the typo should be corrected. |

# 4 PUCCH Format 0/1 Sequence Type

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

|  |  |
| --- | --- |
| **Company** | **Company Proposals** |
| Intel | **Proposal 2: For PUCCH format 0 and 1, the sequence is generated by using a computer-generated sequence or Zadoff-Chu sequence of length equal to the number of subcarriers over which the PUCCH spans across.** |
| Ericsson | **Proposal 2** Reuse the Rel-15 rules to select base sequences for Rel-17 enhanced PUCCH format 0, 1 and 4 with multiple RBs, i.e., based on Low-PAPR sequence Type-1 defined in 38.211 Section 5.2.2. |
| vivo | **Proposal 3: The RE and sequence mapping pattern of multi-sub-PRB based PUCCH needs further study.** |
| Futurewei | [**Proposal 1** **To** **increase the spectrum utilization, especially**](#_Toc53775918) **for high-power equipment, multiple RBs should be used for PF0/1/4. Longer sequence or repetition in frequency-domain should be considered.**  [Proposal 3 For the PAPR concern, the](#_Toc53775918) length-12NRB sequence offers sufficiently low PAPR and is preferred over sequence repetition over a length-NRB sequence, given RB extension is allowed for PF 0 for NR-U 52.6 to 71GHz.  [Proposal 4 Consider](#_Toc53775918) evaluating the applicability of the new sequences designed under R17 coverage enhancement for NR-U 52.6 to 71GHz and further redesigns, given that the RB extension for PF0/1/4 is supported. |
| Lenovo, MoM | ***Proposal 2: For NR operation between 52.6 GHz and 71 GHz, frequency domain repetition should be supported for mapping to multiple RBs for PUCCH format 0/1/4***  ***Proposal 3: For NR operation between 52.6 GHz and 71 GHz, PUCCH format 0 with longer base sequence (more than length 12) should be supported for mapping to multiple RBs***  ***Proposal 4: For NR operation between 52.6 GHz and 71 GHz, PUCCH format 0 transmitted with multiple number of (same) base sequences should be supported for mapping to multiple RBs***  ***Proposal 6: For NR operation between 52.6 GHz and 71 GHz, PUCCH format 1 with longer orthogonal code (longer than the configured OFDM symbols for PUCCH) should be supported for mapping to multiple RBs***  ***Proposal 6: For NR operation between 52.6 GHz and 71 GHz, PUCCH format 1 with longer orthogonal code (longer than the configured OFDM symbols for PUCCH) should be supported for mapping to multiple RBs*** |
| Qualcomm | **Proposal 2: NR should re-use the same base sequence generation procedure as in EPUCCH in NR-U FR1 for a PUCCH Format 0/1 in 60GHz unlicensed band if a PUCCH format 0/1 resource is configured with more than one RB.** |
| ZTE | **Proposal 1: Reuse the sequence based PUCCH format 0/1, further study on the sequence type and length based on CM/PAPR, detection performance and coverage analysis to select between CGS extended sequence and ZC sequence is needed.** |
| Huawei | ***Proposal 3: The Alternatives 1a/1b/2 identified for enhanced PUCCH format 0/1 in NR-U Rel-16 should be the starting point and be re-evaluated for the new SCS and different number of PRBs in the frequency band from 52.6 GHz to 71 GHz.*** |
| LGE | **Proposal #3: For multi-PRB based PUCCH format 0/1, consider the single long PUCCH sequence with contiguous mapping or PUCCH sequence by frequency domain repetition with an appropriate PAPR mitigation technique.** |
| Nokia | ***Proposal 3:*** *Contiguous multi-RB allocation is supported for PUCCH format 0 and format 1 by using type 1 low-PAPR sequences either of length or of length repeated for each RB with a RB dependent cyclic shift component.* |
| Samsung | **Proposal 2: Support contiguous multi-PRB PUCCH format 0/1 by reusing the design of NR-U PUCCH format 0/1, i.e. single-PRB sequence repetition and Cyclic Shift hopping among multiple PRBs.** |
| CATT | **Proposal 2** The method to reduce the PAPR can be discussed if repetitive sequences are supported. |
| Apple | ***Proposal 3:*** *RAN1 to specify sequences of length N* x *12 for PUCCH formats 0/1/4 with N PRBs and decide how the increased resources used for PUCCH transmission should be used.* |
| Interdigital | ***Proposal 2:*** *For new sequence design and frequency domain repetition, scenarios, potential approaches (e.g., reusing Rel-15/16 CGS/ZC/Gold/m-sequences generation with desired sequence lengths), performance metrics for evaluations and PAPR reduction techniques studied in NR coverage enhancement SI can be a starting point, if needed.*  ***Proposal 3:*** *Further study on possible solutions for enhancement of PUCCH formats 0/1/4 other than time domain repetition.* |
| WILUS | * *Proposal 2: For the case of sequence based PUCCH format 0/1, time/freq. domain repetition considering coherent bandwidth for the new numerologies 480kHz and 960kHz should be further investigated to compensate for PSD limitation per MHz in 60GHz unlicensed spectrum.* |
| MediaTek | **Proposal 2: Potential enhancements for PUCCH format 0/1/4 transmissions to achieve higher transmit power by repetition in frequency domain with PAPR mitigation schemes and longer sequence than length 12 for PUCCH format 0/1 can be considered.** |
| Speadtrum | ***Proposal 2: Rel-16 NR-U enhanced PUCCH format 0 and 1 could be the start point for the enhancement of multi-PRB allocation PUCCH format 0 and 1.*** |
| OPPO | **Proposal 3: adopt NRU-like phase cycling concept for PRB-based PUCCH allocation. FFS for sub-PRB based PUCCH allocation** |

Based on company contributions, two main alternatives are identified for enhanced (multi-RB) PF0/1. The first is based on extending the length of a Type-1 low-PAPR sequence to match the number of Res in multi-RB PF0/1. Type-1 low-PAPR sequence generation is described in 38.211 Section 5.2.2, which is used for PUCCH formats 0 and 1 in Rel-16. The other approach is to repeat a length-M Type-1 low-PAPR sequence in each of the PRBs (where M <= 12), and using an appropriate PAPR/CM mitigation approach as was specified for interlaced PF0/1 in Rel-16.

The following is proposed, which could be agreed independently from the proposal in Section 3.1 on frequency domain resource mapping.

1. Agree to the following

For enhanced (multi-RB) PUCCH Formats 0/1 for 120/480/960 kHz SCS, support Type-1 low PAPR sequences. Further discuss the following alternatives for sequence construction:

* Alt-1: A single sequence of length equal to the total number of mapped Res of of the PUCCH resource is used. Cyclic shifts are defined in the same was 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 PRB of the PUCCH resource is used, and the sequence is repeated in each PRB. 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

## 4.1 <1st Round Comments>

Please provide your company view on the above proposal

|  |  |
| --- | --- |
| **Company** | **View/Position** |
| Qualcomm | Alt2 is preferred for for the reason of simplicity |
| OPPO | Alt-2 is preferred. |
| Intel | We are supportive of the current proposal, and our preference is for Alt-1 given that based on our evaluations this provides clear advantages in terms of PAPR and CM for all SCS. |
| Apple | We prefer Alt-1 |
| vivo | Support proposal 4 to FFS on Alt-1 and Alt-2. |
| Futurewei | Agree with vivo that further study is necessary to evaluate the PAPR and CM of solutions. |
| InterDigital | Agree with vivo and Futurewei that further study is needed. |
| Samsung | Agree with proposal 4. When comparing these 2 alternatives, both performance and potential standard effort should be considered.  Besides, similar to PUCCH format 4, whether or not the PRBs of enhanced (multi-RB) PF0/1 are aligned for users that are multiplexed also affects the sequence design selection in order to ensure orthogonality between multiplexed users. |

# 5 PUCCH Format 4

## 5.1 Sequence Type for DMRS

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

|  |  |
| --- | --- |
| **Company** | **Company Proposals** |
| Ericsson | **Proposal 2** Reuse the Rel-15 rules to select base sequences for Rel-17 enhanced PUCCH format 0, 1 and 4 with multiple RBs, i.e., based on Low-PAPR sequence Type-1 defined in 38.211 Section 5.2.2. |
| Futurewei | [**Proposal 1** **To** **increase the spectrum utilization, especially**](#_Toc53775918) **for high-power equipment, multiple RBs should be used for PF0/1/4. Longer sequence or repetition in frequency-domain should be considered.** |
| Lenovo, MoM | ***Proposal 2: For NR operation between 52.6 GHz and 71 GHz, frequency domain repetition should be supported for mapping to multiple RBs for PUCCH format 0/1/4*** |
| Samsung | **Proposal 4: Support multi-PRB PUCCH format 4 by reusing PUCCH format 3 with minor modification:**   * **Pre-DFT OCC across contiguous multiple PRBs for UCI** * **FFS using single long sequence over multiple PRBs or single-PRB sequence repetition over multiple PRBs for DMRS, depending on whether support multiplexing between UEs with non-aligned PRBs.**   **Do not support PRB scaling according to UCI payload and configured coding rate.** |
| CATT | **Proposal 3** For format 4, the sequence in NR can be simply reused via removing the restriction on sequence length. |
| Apple | ***Proposal 3:*** *RAN1 to specify sequences of length N* x *12 for PUCCH formats 0/1/4 with N PRBs and decide how the increased resources used for PUCCH transmission should be used.* |
| Interdigital | ***Proposal 2:*** *For new sequence design and frequency domain repetition, scenarios, potential approaches (e.g., reusing Rel-15/16 CGS/ZC/Gold/m-sequences generation with desired sequence lengths), performance metrics for evaluations and PAPR reduction techniques studied in NR coverage enhancement SI can be a starting point, if needed.*  ***Proposal 3:*** *Further study on possible solutions for enhancement of PUCCH formats 0/1/4 other than time domain repetition.* |

Based on company contributions, two main alternatives are identified for enhanced (multi-RB) PF4. The first is based on extending the length of a Type-1 low-PAPR sequence for DMRS to match the number of REs in multi-RB PF4. Type-1 low-PAPR sequence generation is described in 38.211 Section 5.2.2. The other approach is to repeat a length-M Type-1 low-PAPR sequence in each of the PRBs (where M<=12) for DMRS, and using an appropriate PAPR/CM mitigation approach as was specified for interlaced PF0/1 in Rel-16.

An additional issue for discussion is raised in [17] regarding whether or not the PRBs of enhanced (multi-RB) PF4 are aligned for users that are multiplexed. This may affect the sequence design selection in order to ensure orthogonality between multiplexed users.

The following is proposed, which could be agreed independently from the proposal in Section 3.1 on frequency domain resource mapping.

1. Agree to the following

For DMRS of enhanced (multi-RB) PUCCH Format 4 for 120/480/960 kHz SCS, support Type-1 low PAPR sequences. Further discuss the following alternatives for sequence construction:

* Alt-1: A single sequence of length equal to the total number of mapped REs of of the PUCCH resource is used. Cyclic shifts are defined in the same was as Rel-15/16 for PF4.
* Alt-2: A single sequence of length equal to the number of mapped REs per PRB of the PUCCH resource is used, and the sequence is repeated in each PRB. 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

Further discuss whether multiplexed UEs shall have aligned PRB allocations or are allowed to have non-aligned (partially overlapping) PRB allocations considering the above alternatives.

### 5.1.1 <1st Round Comments>

Please provide your company view on the above proposal.

|  |  |
| --- | --- |
| **Company** | **View/Position** |
| qualcomm | Alt-1 which is similar to DMRS sequence for other channels |
| OPPO | Alt-2 is preferred. |
| Intel | We are supportive of the current proposal. |
| Apple | We prefer Alt-1 |
| vivo | Support proposal 5. |
| Futurewei | We are supportive of the current proposal , including FFS for down-selection. |
| InterDigital | We are fine with the proposal. |
| Samsung | We support proposal 5. |

## 5.2 DFT Precoding and OCC Mapping

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

|  |  |
| --- | --- |
| **Company** | **Company Proposals** |
| Intel | **Proposal 4: Enhance UE multiplexing for PUCCH format 4 by applying the pre-DFT block-wise OCC spread across the entire transmission bandwidth on UCI symbols.** |
| vivo | Proposal 5: The parameter related to block-wise spreading for PUCCH format 4 is dependent on the number of RBs and the number of REs in each RB. |
| Huawei | ***Proposal 4: The following two alternatives to enhance PUCCH format 4 can be considered in the frequency band from 52.6 GHz to 71 GHz***  ***Alt. 1: One DFT-precoder per PRB***  ***The following PAPR/CM reduction methods are considered:***   * ***PRB-specific modulation symbol interleaving*** * ***PRB-specific multiplication with a complex value*** * ***PRB-specific phase rotation*** * ***PRB-specific scrambling***   ***Alt. 2: One DFT-precoder for all PRBs***  ***No further PAPR/CM reduction is considered.*** |
| LGE | **Proposal #4: For multi-PRB based PUCCH format 4, it should discussed how the pre-DFT OCC with increased length (compared to Rel-15 PUCCH format 4) can be applied on multiple PRBs.** |
| Nokia | ***Proposal 4:*** *PUCCH format 4 applies the same intra-symbol block-wise spreading also when allocated with multiple contiguous RBs.* |
| Samsung | **Proposal 4: Support multi-PRB PUCCH format 4 by reusing PUCCH format 3 with minor modification:**   * **Pre-DFT OCC across contiguous multiple PRBs for UCI** * **FFS using single long sequence over multiple PRBs or single-PRB sequence repetition over multiple PRBs for DMRS, depending on whether support multiplexing between UEs with non-aligned PRBs.**   **Do not support PRB scaling according to UCI payload and configured coding rate.** |

PUCCH format 4 in Rel-15/16 uses pre-DFT blockwise spreading using OCCs to support user multiplexing. Several companies have discussed how this can be extended to enhanced (multi-RB) PF4. Some companies observe that the same approach as used for PF3 can be reused, whereas others suggest that changes are needed for the case of multiple RBs. One company also lists two alternatives for pre-DFT blockwise spreading, one based based on blockwise spreading over the entire PUCCH transmission bandwidth, and another based on per-PRB that requires a PAPR/CM reduction approach.

1. Agree to the following

For UCI of enhanced (multi-RB) PUCCH Format 4 for 120/480/960 kHz SCS, support pre-DFT blockwise spreading based on OCCs. Further discuss the details, including the following:

* Supported OCC lengths, e.g., 2 and 4 as in Rel-15/16 PF4
* Whether or not the same approach as for Rel-16 interlaced PF3 is reused for multi-RB PF4
  + Note: blockwise spreading is performed across entire PUCCH transmission bandwidth
* If the same approach is not reused, what adaptations are needed

### 5.2.1 <1st Round Comments>

Please provide your company view on the above proposal.

|  |  |
| --- | --- |
| **Company** | **View/Position** |
| Moderator | It is the moderator's understanding that if N\_RB contiguous RBs are supported with all REs within each PRB mapped to PUCCH, then exactly the same pre-DFT approach as supported for Rel-16 interlaced PF3 can be reused for multi-RB PF4. The only adaptation that is needed is that the number of RBs N\_RB is configurable, and should fulfil where is a set of non-negative integers. |
| Qualcomm | Support. Reuse EPF3 design other than interlace |
| OPPO | We think the same approach as for Rel-16 interlaced PF3 should be reused for multi-RB PF4. |
| Intel | We are generally Ok with the proposal. However, we think that another factor that RAN1 should also take into account when enhancing the PUCCH format 4 is its multiplexing capacity, and whether any additional spreading factors compared to those currently supported (i.e., 2, and 4) are needed. Therefore, we propose to add an additional FFS (in red) as follows:   * Supported OCC lengths, e.g., 2 and 4 as in Rel-15/16 PF4   FFS on other OCC lengths |
| Apple | Supported OCC lengths, e.g., 2 and 4 as in Rel-15/16 PF4 |
| vivo | Support proposal 6. |
| Futurewei | Support the proposal. |
| MediaTek | Support reusing Rel-16 PF3 design. |
| InterDigital | We are fine with the proposal. |
| Samsung | We supprort the proposal. |

# 6 PUCCH Resource Sets Prior to RRC Configuration

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

|  |  |
| --- | --- |
| **Company** | **Company Proposals** |
| 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.** |
| Qualcomm | **Proposal 4: For initial access, gNB should support multiple bandwidths of PUCCH format 0/1, and UE indicates selecting of PUCCH bandwidth by using different PRACH resources provided by gNB.** |
| LGE | **Proposal #2: 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** |
| Nokia | ***Proposal 2:*** *PUCCH resource sets provided by the pucch-ResourceCommon are enchanced to support several allocation options for the number of RBs.* |
| Samsung | **Proposal 3: Support contiguous multi-PRB PUCCH format 0/1 before RRC connection setup**   * **support different number of multiple PRBs for different scenarios.** * **support different number of multiple PRBs for different UEs.** |

Several companies have discussed enhancements to the PUCCH resource set used prior to RRC configuration, e.g., for HARQ-ACK of Msg 2/4. In Rel-15/16, the PUCCH resource set includes 16 PUCCH resources that are multiplexed in the frequency domain and code domain (through cyclic shifts). Some companies have observed that depending on the number of RBs allowed for PF0/1 for PUCCH used prior to RRC configuration, as well as the supported SCS(s) and sizes of the initial UL BWP, it may not be possible to support a sufficient number of disjoint allocations in the frequency domain to make up a set of 16 PUCCH resources.

Due to the dependencies on the number of RBs supported for PF0/1 and the supported SCS(s) and sizes of an initial UL BWP, it is hard to make progress in this area for now. Hence, it is recommended that this topic should be revisited at a later time once progress has been made on the number of RBs.

1. The following is recommended

Revisit the design of the PUCCH resource set used prior to RRC configuration once more progress is made on the design of enhanced (multi-RB) PF0/1, e.g., # of supported RBs, as well as the supported SCS(s) and size(s) of an UL initial BWP.

## 6.1 <1st Round Comments>

While it is unlikely that progress will be made on this topic during this meeting, companies are still free to provide their view in the following if so desired. This can always help for future discussions.

|  |  |
| --- | --- |
| **Company** | **View/Position** |
| Qualcomm | Support to revisit to take advantage of the higher power PUCCH for initial access |
| OPPO | Agree to revisit the design of the PUCCH resource set for UE in initial access procedure. |
| Intel | We are OK to postpone the discussion to the following meeting. However, we would like to point out that when PUCCH format 0 and 1 are enhanced so that they span across a number of PRBs larger than 1, for some numerologies (i.e., subcarrier spacing and bandwidth), and some of the NR PUCCH resources sets, the total number of PRBs used for the transmission of a PUCCH is so large that the PUCCH resource partitioning in frequency domain is no longer possible.  As an example, let’s consider the case when 960 kHz subcarrier spacing is used with a bandwidth of 400 MHz. In this case the total number of available PRBs would be approximately 32 PRBs. If a PUCCH format 1 is configured to be able to operate in Europe with the maximum transmit power, then the PUCCH should span over at least 5 PRBs. If frequency hopping is used, then 10 PRBs will be occupied by each resource set. For each of the resource set groups composed by more than 2 orthogonal resource sets the number of PRBs required would be greater than the one available: for instance, for the groups composed by {index4, index5, index6} and {index8, index9, index10} then a minimum of 36 PRBs would be needed, while for the group composed by {index12, index13, index14, index 15}, a minimum of 48 PRBs would be needed.  Therefore we think that RAN1 should indeed discuss how to enhance the PUCCH common resource sets (e.g., via either additional starting symbols or orthogonal cover codes) so that for each resource group at least the same number of orthogonal resources are supported. |
| Apple | We agree that the design should be revisited. |
| vivo | We prefer to study this only after evaluations to justify the need of such revistit of the design of the PUCCH resource set used prior to RRC configuration. |
| Futurewei | We are OK with the proposal to revisit at a later time. |
| InterDigital | We are fine with the proposal. |
| Samsung | We support revisit the design of the PUCCH resource set prior to RRC configuration. Besides, we’d like to also invite companies to show the views that whether and how to support different number of PRBs for different UEs in the same serving cell. |

# References

1. RP-202925, “Revised WID on Extending current NR operation to 71 GHz,” CMCC, RAN#90, December 2019.
2. 3GPP TR 38.808, “Study on supporting NR from 52.6 GHz to 71 GHz,” v0.2.0, November 2020.
3. Chairman Notes (Section 7.2.2.1.3), RAN1#96b, April 2019.
4. R1-2100059 Enhancements to PUCCH formats 0/1/4 for NR from 52.6 GHz to 71GHz Lenovo, Motorola Mobility
5. R1-2100075 Discussion on the PUCCH enhancements for 52.6 to 71GHz ZTE, Sanechips
6. R1-2100151 Discussion on enhancements for PUCCH format 0/1/4 OPPO
7. R1-2100239 Enhancement on PUCCH formats Huawei, HiSilicon
8. R1-2100259 Enhancements for PUCCH formats Nokia, Nokia Shanghai Bell
9. R1-2100372 Enhancements for PUCCH formats for up to 71GHz operation CATT
10. R1-2100431 Discussions on PUCCH enhancements for NR operation from 52.6GHz to 71GHz vivo
11. R1-2100487 Discussion on PUCCH Channel enhancements FUTUREWEI
12. R1-2100609 PUCCH formats 0/1/4 enhancement for 52.6-71 GHz NR operation MediaTek Inc.
13. R1-2100645 Discussion on PUCCH enhancements for extending NR up to 71 GHz Intel Corporation
14. R1-2100819 Discussion on enhancements for PUCCH format 0/1/4 for above 52.6GHz Spreadtrum Communications
15. R1-2100838 Discussions on enhancements for PUCCH formats 0/1/4 InterDigital, Inc.
16. R1-2100894 Enhancements for PUCCH formats 0/1/4 to support NR above 52.6 GHz LG Electronics
17. R1-2101196 Enhancements for PUCCH format 0/1/4 for NR from 52.6 GHz to 71 GHz Samsung
18. R1-2101308 PUCCH enhancements Ericsson
19. R1-2101374 Enhancements for PUCCH formats 0/1/4 for NR between 52.6GHz and 71 GHz Apple
20. R1-2101455 Enhancements for PUCCH for NR in 52.6 to 71GHz band Qualcomm Incorporated
21. R1-2101607 PUCCH format 0/1/4 enhancements for NR from 52.6 to 71 GHz NTT DOCOMO, INC.
22. R1-2101673 Discussion on PUCCH enhancement for PUCCH format 0/1/4 WILUS Inc.