**3GPP TSG RAN WG1 #103-e R1-200xxxx**

**e-Meeting, October 26th – November 13th, 2020**

**Agenda item:** 8.8.2.2

**Source:** Moderator (Qualcomm)

**Title:** FL summary of PUCCH coverage enhancement

**Document for:** Discussion/Decision

# Introduction

In this document, a summary of companies’ view on potential techniques for PUCCH coverage enhancement is provided.

# Summary of study on prioritized schemes

## Sequence based DMRS-less PUCCH

Ten companies have provided LLS results for this scheme. The following table is firstly extracted from R1-2007483 “[102-e-Post-NR-CovEnh-02] Phase 3: initial collection of simulation results for enhancements” [23], followed by adding new results submitted to RAN103e in [1][10].

Table 1: Performance gain observed for sequence based DMRS-less PUCCH

|  |  |  |
| --- | --- | --- |
| Company | Observed performance gain | Key simulation assumptions |
| ZTE | 2 ~ 3 dB SNR gain | 11 bits UCI, w/o DTX detection, 1% BLER  Receiver for Rel-15/16 PUCCH: ML coherent receiver  Receiver for sequence based PUCCH: ML noncoherent sequence detector |
| Intel | -1.0 ~ 0.2 dB SNR gain | 3/11 bits UCI, w/ DTX detection, 1% FA, 1% BLER,  Receiver for Rel-15/16 PUCCH: ML coherent receiver  Receiver for sequence based PUCCH: ML noncoherent sequence detector/correlator |
| Qualcomm | 3 ~ 4 dB SNR gain  3.5dB PAPR gain w/ QPSK  0.5dB PAPR gain w/ Pi/2 BPSK | 2 bits UCI, w/ DTX detection, 1% FA, 1% ACK miss, 0.1% NACK->ACK error  4 bits UCI, w/o DTX detection, 1% BLER  11 bits UCI, w/o DTX detection, 1% BLER  11 bits UCI, w/ DTX detection, 1% FA, 1% BLER  Receiver for Rel-15/16 PUCCH: ML coherent receiver  Receiver for sequence based PUCCH: ML noncoherent receiver (correlator with 2D-FFT or fast Hadamard transform) |
| Sharp | 3 dB | 4 bits UCI, w/o DTX detection, 1% BLER  Receiver for Rel-15/16 PUCCH: MMSE channel estimation (with genie Doppler and delay spread) + ML coherent detection  Receiver for sequence based PUCCH: ML noncoherent sequence detector/correlator |
| CMCC | 1 ~ 2.7dB | 11 bits UCI, w/o DTX detection, 1% BLER  Receiver for Rel-15/16 PUCCH: ML coherent receiver  Receiver for sequence based PUCCH: ML noncoherent sequence detector/correlator |
| vivo | 0.3 ~ 0.5dB | 6 bits UCI, w/ DTX detection, 1% FA, 1% BLER  Receiver for Rel-15/16 PUCCH: ML noncoherent detector  Receiver for sequence based PUCCH: ML noncoherent sequence detector/correlator |
| Ericsson | 0 ~ 0.2dB | 11 bits UCI, w/o DTX detection, 1% BLER  Receiver for Rel-15/16 PUCCH: advanced receivers (with data aided channel estimation?)  Receiver for sequence based PUCCH: not reported yet |
| EURECOM | 1.5 ~ 2.1dB (Coding gain)  4.8 dB (PAPR gain) | 4/11 bits UCI, w/o DTX detection, 1% BLER  Receiver for Rel-15/16 PUCCH: advanced receivers (joint detection/estimation)  Receiver for sequence based PUCCH: ML noncoherent sequence detector/correlator |
| Huawei, HiSi | 3 ~ 4dB  4.5dB (PAPR gain) | 11 bits UCI, w/o DTX detection, 1% BLER  2 bits UCI, w/ DTX detection, 1% FA, 1% ACK miss, 0.1% NACK->ACK error  Receiver for Rel-15/16 PUCCH: 2D-Wiener filter based channel estimation + MMSE equalization  Receiver for sequence based PUCCH: CHIRRUP algorithm based sequence detection |
| OPPO | ~3dB | 2 bits UCI, w/ DTX detection, 1% FA, 1% ACK miss, 0.1% NACK->ACK error. The format 1 is in our contribution of R1-2008269.  LMMSE-IRC receiver for format 1. ML correlation for DMRS-less. |

Besides the LLS simulations to study the gain of the scheme, a few other aspects of the schemes are also discussed/studied:

* The spec impact of the scheme is discussed in [1][4][6]
* The receiver complexity with the scheme is studied/discussed in [1][15][18][19]
* The receiver sensitivity to time and frequency error is studied in [18]

## PUSCH repetition Type-B like PUCCH repetition

One company provided LLS results for this scheme. The following table is extracted from [23].

Table 2: Performance gain observed for PUSCH repetition Type-B like PUCCH repetition

|  |  |  |
| --- | --- | --- |
| Company | Observed performance gain | Key simulation assumptions |
| VIVO | 0.5dB (w/o DMRS bundling)  1~1.5dB (w DMRS bundling) | 11 bits UCI, w/o DTX detection, 1% BLER |

Besides the LLS simulations to study the gain of the scheme, a few other aspects of the schemes are also discussed/studied:

* The spec impact of the scheme is discussed in [4][6]
* Restrictions to apply the scheme in certain scenarios such as >11 bits UCI [4]
* Some design details of the scheme are discussed in [9][20]

## (Explicit or implicit) Dynamic PUCCH repetition factor indication

Two companies provided simulation results for this scheme. The following table is extracted from [23].

Table 3: Performance gain observed for PUSCH repetition Type-B like PUCCH repetition

|  |  |  |
| --- | --- | --- |
| Company | Observed performance gain | Key simulation assumptions |
| Ericsson | 5 dB (with repetition factor 8) | 11 bits CSI, w/o DTX detection, 10% BLER |
| ZTE | Reducing the number of PUCCH repetitions for more than 70% cases. | 11 bits UCI, w/o DTX detection, 1% BLER |

A point was raised in [19] that this scheme cannot be considered as an independent solution for PUCCH coverage enhancement, because this is only a scheme to enhance signalling which does not offer extra coverage.

## DMRS bundling cross PUCCH repetitions

Three companies provided LLS results for this scheme. The following table is extracted from [23].

Table 4: Performance gain observed for PUSCH repetition Type-B like PUCCH repetition

|  |  |  |
| --- | --- | --- |
| Company | Observed performance gain | Key simulation assumptions |
| ZTE | 1 dB | 22 bits UCI, w/o DTX detection, 1% BLER, 4 PUCCH repetitions |
| Intel | ~1.2 dB | 22 bits UCI, w/o DTX detection, 1% BLER, 8 PUCCH repetitions |
| VIVO | 0.85 ~ 1.3 dB | 11 bits UCI, w/o DTX detection, 1% BLER, 2 PUCCH repetitions |

To allow DMRS bundling, one prerequisite is the phase coherency cross PUCCH repetitions. This issue was mentioned in a few contributions. It is suggested in [12] to send LS to RAN4 to ask under what conditions UE can keep phase coherence cross repetitions.

## FL proposals for prioritized schemes

Based on the input from companies, the following is proposed.

**Proposed conclusion**: **For the prioritized schemes agreed in RAN1 102e for PUCCH coverage enhancement, further study and conclude in RAN1 103e the following aspects:**

* **Use case/restriction/prerequisite of the schemes**
* **Performance gains including SINR gain (to achieve the required BLER) and PAPR/CM gain**
* **Potential spec impact of the schemes**
* **Impact to base station receiver implementation including receiver complexity and sensitivity to time and frequency error**
* **Impact to UE implementation**
  + **Send LS to RAN4 for identified RAN4 related issue if any.**

Table 5: Comments to the FL proposal

|  |  |
| --- | --- |
| Company | Comments |
| vivo | We suggest to remove ‘sensitivity to time and frequency error’, and it can be reported in performance gains if needed. |
| Intel | We suggest to add the performance metric in the conclusion, i.e., 1% DTX to ACK probability as this is RAN4 requirement for all PUCCH formats carrying HARQ-ACK feedback. |

# Summary of study on other schemes

The study results on other schemes for PUCCH coverage enhancement are captured in Section 3.2 in [23], and copied as below.

Table 6: Performance gain observed for other PUCCH coverage enhancement schemes

|  |  |  |
| --- | --- | --- |
| Company | Solutions | Performance gain |
| CATT | One antenna precoder cycling | 1 dB |
| IITH, IITM, CEWIT, Reliance Jio, Tejas Networks | Power boosting for pi/2 BPSK | 3 dB for <50% UL duty cycle |
| 6 dB for <25 % UL duty cycle |
| Qualcomm | UCI payload compression (FR2 L1 beam report) | Helps increase reliability of beam switching procedure |
| NTT DOCOMO | Repetition for PUCCH format 2 | 1.5 dB |
| Ericsson | Aperiodic CSI on PUCCH | 3.5 dB MIL  5.0 dB LLS |

# Further discussion

The next phase is to have more technical discussions on each proposed technique. For each scheme, companies are welcome to express feedback and comments to further discuss the LLS gain, PAPR gain, the spec impact, and the impact to receiver implementation.

## ~~Sequence based~~ DMRS-less PUCCH

Companies are welcomed to provide views in the following table to identify the pros. and cons. of this scheme.

Table 7: Comments on the “~~Sequence based~~ DMRS-less PUCCH”

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Company:  Qualcomm | | Use case of the scheme: Can be used in place of PF3 for small payloads (2-22 bits). Also applicable in place of PF2. | | | |
| Any Restriction to apply the scheme: primarily intended for small payloads | | | |
| Any prerequisite to apply the scheme: none | | | |
| Performance gain | | SNR gain: 3-4 dB | |
| PAPR/CM gain: 0.5 dB over R15 PF3 with pi/2 BPSK. 3.5 dB over R15 PF3 with QPSK. | |
| Spec impact: New PUCCH Format needs to be introduced. | | | |
| Impact to receiver | | Receiver complexity: No need for DMRS channel estimation. Sequence detection needs to be implemented --- computationally efficient implementations available for certain choice of sequences, e.g. m-sequences. | |
| Receiver sensitivity to time/frequency error: more robust to timing and frequency than NR PUCCH. | |
| Impact to UE implementation | | Simple tx implementation. No explicit encoder needed. Can leverage sequence design methods that are already specified in NR. | |
| Company:  CATT | | Use case of the scheme: Could be used to replace PF3 and PF4 if the coverage cannot be guaranteed by other techniques. | | | |
| Any Restriction to apply the scheme: The UCI payload cannot be too large. | | | |
| Any prerequisite to apply the scheme: | | | |
| Performance gain | | SNR gain: | |
| PAPR gain: | |
| Spec impact: new PUCCH format needs to be introduced. The resource allocation, the sequence design, the carrying UCI payload need to be further studied. | | | |
| Impact to receiver | | Receiver complexity: Depends on the detail sequence design, the receiver complexity may be increased. | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | | Depends on the detail sequence design. May complicate UE implementation. | |
| Company:  NTT DOCOMO | | Use case of the scheme: The technique can be applied for PF2 for FR2 operation with large number of gNB antenna beams as well as for PF 1/3/4 for FR1 operation. | | | |
| Any Restriction to apply the scheme: | | | |
| Any prerequisite to apply the scheme: | | | |
| Performance gain | | SNR gain: | |
| PAPR/CM gain: | |
| Spec impact: | | | |
| Impact to receiver | | Receiver complexity: | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | |  | |
| Company:  Panasonic | | Use case of the scheme: Replacement of PUCCH format which is coverage bottleneck, especially PUCCH format 3. | | | |
| Any Restriction to apply the scheme: Applicable for low/medium UCI payload size | | | |
| Any prerequisite to apply the scheme: | | | |
| Performance gain | | SNR gain: | |
| PAPR/CM gain: | |
| Spec impact: New PUCCH format needs to be introduced. Sequence design/selection, the applicable payload size should be specified. | | | |
| Impact to receiver | | Receiver complexity: ML non-coherent sequence detection may increase the receiver complexity. | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | | No encoder is needed. | |
| ZTE | | Use case of the scheme: For UCI payload of 3~11 bits for long PUCCH format | | | |
| Any Restriction to apply the scheme: Only for medium payload size | | | |
| Any prerequisite to apply the scheme: | | | |
| Performance gain | | SNR gain: 2 ~ 3 dB | |
| PAPR gain: | |
| Spec impact: Define related sequences and PUCCH resource configuration | | | |
| Impact to receiver | | Receiver complexity: No need for DMRS channel estimation. Blind detection on sequence transmitted from a sequence pool. | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | | Implement a new PUCCH format | |
| Company:  Sharp | | Use case of the scheme: Small payload (e.g., up to 11 bits) transmission | | | |
| Any Restriction to apply the scheme: None | | | |
| Any prerequisite to apply the scheme: None | | | |
| Performance gain | | SNR gain: 3 dB | |
| PAPR/CM gain: | |
| Spec impact: Introduce new PUCCH format (including complex-value sequence generation, resource mapping) | | | |
| Impact to receiver | | Receiver complexity: Need to modify sequence detector for PUCCH format 0 for more than 2 bits. | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | | UE is required to implement a sequence generator. UE implementation effort can be reduced by reusing conventional sequence (e.g., low PAPR sequence) | |
| Company:  IITH, IITM, CEWIT, Reliance Jio, Tejas Networks | | Use case of the scheme: Match the control channel coverage and PAPR with that of PUSCH. Pi/2 BPSK can be used for PF2 re-design and PF3 re-design. | | | |
| Any Restriction to apply the scheme: Smaller payloads can be used | | | |
| Any prerequisite to apply the scheme: | | | |
| Performance gain | | SNR gain: | |
| PAPR/CM gain: | |
| Spec impact: Introduce new PUCCH format or enhance existing ones to support larger payloads, define sequences which can be used for the same. | | | |
| Impact to receiver | | Receiver complexity: Can avoid DMRS based estimation | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | | Reuse existing methods of receiver implementation | |
| Company:  CMCC | | Use case of the scheme: could be used to replace PF3 for small payload. | | | |
| Any Restriction to apply the scheme: low UCI payload | | | |
| Any prerequisite to apply the scheme: | | | |
| Performance gain | | SNR gain: 1~2.7dB | |
| PAPR/CM gain: | |
| Spec impact: new PUCCH format should be introduced. UCI payload, sequence design, resource allocation | | | |
| Impact to receiver | | Receiver complexity: depends on sequence design and sequence length  While with shorter sequence compared to the case that all REs in the PUCCH resource are used to carry a whole long sequence, and less number of sequence detections, the receiver complexity is reduced. | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | | Depends on the sequence design and UCI payload | |
| Company:  OPPO | | Use case of the scheme: Mainly about the small payload size 1~2bits, HARQ-operation with potentially TB bundling. The consideration is for coverage limited cases, the coverage is determined by the small payload PUCCH. Larger payload can be further considered. | | | |
| Any Restriction to apply the scheme: None | | | |
| Any prerequisite to apply the scheme: None | | | |
| Performance gain | | SNR gain: ~3dB | |
| PAPR/CM gain: FFS | |
| Spec impact: Extending the current PUCCH format or introducing new format. | | | |
| Impact to receiver | | Receiver complexity: ML (Exsiting) | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | | Small | |
| Company:  LG | | Use case of the scheme: DMRS-less (not a sequence based, only DMRS is removed) PUCCH can be applied to long PUCCH configured with repetition when the resource for it is not sufficient and adjacent slot of it contains DMRS which enables channel estimation. | | | |
| Any Restriction to apply the scheme: long PUCCH | | | |
| Any prerequisite to apply the scheme: none | | | |
| Performance gain | | SNR gain: expected to be increased by the amount of removed DMRS of the slot since the adjacent slot which contains DMRS can help channel estimation | |
| PAPR/CM gain: | |
| Spec impact: minimal | | | |
| Impact to receiver | | Receiver complexity: no additional complexity is required | |
| Receiver sensitivity to time/frequency error: none | |
| Impact to UE implementation | | Minimal | |
| Company:  vivo | | Use case of the scheme: PUCCH with less or equal to 11bits | | | |
| Any Restriction to apply the scheme:  Limited number of bits can be delivered. Otherwise, it will lead to high detection complexity. | | | |
| Any prerequisite to apply the scheme:  Performance gain can be achieved compared with legacy PF3 with advanced receiver | | | |
| Performance gain | | Performance gain | |
| PAPR/CM gain: | |
| Spec impact:  A new PUCCH format should be introduced.  New sequence design would be needed.  How to multiplex CSI/HARQ-Ack to a sequence based PUCCH should be considered in TS 38.213. For example, when CSI is multiplexed with HARQ-Ack, the CSI part is dropped based on the configured coding rate of PUCCH. What is the definition of coding rate of a sequence based PUCCH need to be clarified.  PUCCH format specific power adjustment component  in power control should be defined in TS 38.213.  Whether and how to support Type-B PUCCH repetition should be discussed.  New RAN4 MPR requirement should be introduced in TS 38.101.  New demodulation requirements should be defined in TS 38.104. | | | |
| Impact to receiver | | Impact to receiver | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | | Impact to UE implementation | |
| Company:  Intel | | Use case of the scheme: PUCCH format 3 | | | |
| Any Restriction to apply the scheme: relatively small payload size, i.e., 3-11 bits | | | |
| Any prerequisite to apply the scheme: decisions should be made based on performance results compared to existing PUCCH format 3 scheme. | | | |
| Performance gain | | SNR gain: -1.0dB for 3-bit UCI payload and 0.2 dB for 11-bit UCI payload compared to existing PF3. | |
| PAPR/CM gain: | |
| Spec impact: a new PUCCH format and sequence design, e.g., existing RM coded sequence with removing the first column of the codeword or other sequences. | | | |
| Impact to receiver | | Receiver complexity: non-coherent detection is needed for sequence based PUCCH. | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | |  | |
| Company: | Use case of the scheme: | | | |
| Any Restriction to apply the scheme: | | | |
| Any prerequisite to apply the scheme: | | | |
| Performance gain | | SNR gain: | |
| PAPR/CM gain: | |
| Spec impact: | | | |
| Impact to receiver | | Receiver complexity: | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | |  | |
|  | |  | |  | |

## PUSCH repetition Type-B like PUCCH repetition

Companies are welcomed to provide views in the following table to identify the pros. and cons. of this scheme.

Table 8: Comments on the “PUSCH repetition Type-B like PUCCH repetition”

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Company:  Qualcomm | | Use case of the scheme: Use case for a cell-edge UE is not very clear. Type-B repetitions originally introduced in eURLLC with latency reduction in mind. Latency is not the primary focus in this SI. If cell-edge UE is scheduled with 14-symbol PUCCH, this scheme brings no benefit. If short PUCCH (PF2) is used for a cell edge UE then, some benefits may be possible. Scope of this scheme needs to be clarified. | | | |
| Any Restriction to apply the scheme: | | | |
| Any prerequisite to apply the scheme: | | | |
| Performance gain | | SNR gain: -- | |
| PAPR/CM gain: -- | |
| Spec impact: Need detailed rules on nominal/actual repetition and handling postponement/cancellation. Potentially new DMRS locations need to be specified. Depending on how repetitions across slot boundaries are handled, phase coherence requirement across slots needs to be specified. | | | |
| Impact to receiver | | Receiver complexity: gNB may need to process multiple repetitions within a single slot. | |
| Receiver sensitivity to time/frequency error: Same as NR PUCCH. | |
| Impact to UE implementation | | UE may need to reencode PUCCH payload several times within a single slot. UE may need to closely track number of repetitions and rules for repetitions. New phase coherence constraints may be imposed based on how repetitions are handled across slot boundaries. | |
| Company:  CATT | | Use case of the scheme: Use case is not clear. Type B repetition is used for reduce latency instead of improving reliability. It can only be used for UCI < 11 bits. It becomes a payload-dependent solution. | | | |
| Any Restriction to apply the scheme: Cannot be used for UCI >11 bits. | | | |
| Any prerequisite to apply the scheme: | | | |
| Performance gain | | SNR gain: | |
| PAPR gain: | |
| Spec impact: As mentioned by Qualcomm, the entire procedure of PUSCH repetition type B needs to be reconsidered for PUCCH. | | | |
| Impact to receiver | | Receiver complexity: Receiver complexity increases as gNB needs to receive multiple pieces of PUCCH and combination is unavoidable. Furthermore, the complexity is too high to be feasible if repetition type B is applied to a UCI > 11 bits. | |
| Receiver sensitivity to time/frequency error: no improvement. | |
| Impact to UE implementation | | UE needs to segment a UCI depending on the UL-DL TDD configuration or the slot boundary. How to choose the recourse set in the sub-slot is also needs to be carefully studied. | |
| Company:  Samsung | | Use case of the scheme: coverage limited cases, cell-edge UEs. It improves UL resource utilization and latency while ensuring reliability.  Similar to PUSCH, and at least for UCI payload less than 12 bits, support more than one repetition within a slot, transmission across the slot boundary and invalid symbols, and different number of PUCCH symbols per slot. Support transmission in all symbols indicated as UL symbols by slot configuration or by SFI.  Support repetitions together with SFI operation and, to avoid restrictions in slot configurations indicated by SFI that the gNB cannot predict in advance, consider whether the UE drops or defers repetitions that cannot be transmitted due to collisions with DL/unavailable symbols indicated by SFI (they are deferred in Rel-15)  Support dynamic indication of the number of PUCCH repetitions. | | | |
| Any Restriction to apply the scheme: | | | |
| Any prerequisite to apply the scheme: | | | |
| Performance gain | | SNR gain: | |
| PAPR gain: | |
| Spec impact: The indication of the number of repetitions for a PUCCH transmission can be provided by the DCI format triggering the PUCCH transmission in case HARQ-ACK information is included. The range of the number of repetitions in the Rel-16 configuration has to be increased beyond a maximum of 8 repetitions.  Text similar to the description of PUSCH Type-B repetitions needs to be added to allow multiple repetitions/different number of symbols per slot. | | | |
| Impact to receiver | | Receiver complexity: gNB may process more than one PUCCH repetition in a slot | |
| Receiver sensitivity to time/frequency error: same as R15/16 PUCCH | |
| Impact to UE implementation | | UE may transmit multiple PUCCH repetition in a slot | |
| Company:  Panasonic | | Use case of the scheme: Use case is unclear. This solution may only be beneficial for short PUCCH repetition. | | | |
| Any Restriction to apply the scheme: | | | |
| Any prerequisite to apply the scheme: | | | |
| Performance gain | | SNR gain: | |
| PAPR/CM gain: | |
| Spec impact: Due to the segmentation, the actual length of PUCCH repetition might be different than what was nominally indicated. Since NR defines PUCCH formats depending on the duration of PUCCH, potential impact would be PUCCH format may be different among the actual repetitions if UE generates the PUCCH based on the actual repetition. Therefore, whether/how to ensure the same PUCCH format among the actual repetition should be studied. | | | |
| Impact to receiver | | Receiver complexity: gNB may need to process multiple repetitions within a single slot. | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | | Segmentation process is needed. | |
| Company:  Sharp | | Use case of the scheme: Utilize available symbols in special and subsequent UL slots | | | |
| Any Restriction to apply the scheme: | | | |
| Any prerequisite to apply the scheme: | | | |
| Performance gain | | SNR gain: | |
| PAPR/CM gain: | |
| Spec impact: How to support repetitions with different time length. | | | |
| Impact to receiver | | Receiver complexity: | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | | Transmission of multiple repetitions with different time length | |
| Company:  CMCC | | Use case of the scheme: improve the coverage of PUCCH and fully use the uplink symbols in the special slot in TDD. Current PUCCH repetition occupies a same number of consecutive symbols in the repeated slots. And the starting symbol of each occupied slot should be the same. This limited the use of the 4 uplink symbol in the special slot and the later 2 full slots in the 2.6GHz configuration. A more flexible resource allocation schemes should be introduced for the PUCCH repetition. | | | |
| Any Restriction to apply the scheme: feasible UCI payload should be considered | | | |
| Any prerequisite to apply the scheme: | | | |
| Performance gain | | SNR gain: depends on the repetition number | |
| PAPR/CM gain: | |
| Spec impact: introduce the PUSCH type B like repetition in PUCCH. Different starting symbol in each slot and maybe different occupied symbols in different slots | | | |
| Impact to receiver | | Receiver complexity: similar with type B repetition. Different resource allocation assumptions in each slot (if the rules are clarified, this is not an issue.). | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | | UCI payload limitation and the predefined resource allocation rule (may not include the slot boundary issue) | |
| Company:  OPPO | | Use case of the scheme: With payload size restriction of 11 bits. The scheme can be used for coverage enhancement of both HARQ-ACK and CSI report. | | | |
| Any Restriction to apply the scheme: URLLC capable UE, which was defined as different set of UE capablility. | | | |
| Any prerequisite to apply the scheme: | | | |
| Performance gain | | SNR gain: | |
| PAPR/CM gain: | |
| Spec impact: New or enhanced repetition schemes. | | | |
| Impact to receiver | | Receiver complexity: | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | | Higher UE processing complexity for mini-slot like resources. | |
| Company:  LG | | Use case of the scheme: when more resource is needed to boost coverage of PUCCH and/or uplink resource is limited due to the TDD frame structure (i.e., S slot). | | | |
| Any Restriction to apply the scheme: | | | |
| Any prerequisite to apply the scheme: | | | |
| Performance gain | | SNR gain: increased due to exploiting resources which was conventionally not. | |
| PAPR/CM gain: | |
| Spec impact: nominal/actual repetition and segmentation of PUCCH should be introduced. | | | |
| Impact to receiver | | Receiver complexity: | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | |  | |
| Company:  vivo | | Use case of the scheme: For TDD PUCCH repeated in S slot and U slot, where 2 UL symbols for Slot. | | | |
| Any Restriction to apply the scheme: | | | |
| Any prerequisite to apply the scheme: TDD spectrum with DL heavy frame structure. | | | |
| Performance gain | | Performance gain | |
| PAPR/CM gain: | |
| Spec impact:   * *Concept of nominal PUCCH repetition and actual PUCCH repetition needs be introduced;* * *Segmentation rule to determine occasions for actual PUCCH repetition and the channel design including UCI and DMRS pattern need be defined for the actual PUCCH repetition*   *A reference number of REs, e.g. number of RE of nominal PUCCH repetition, is used to determine the transmission power of actual PUCCH repetition.* | | | |
| Impact to receiver | | Impact to receiver | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | | Impact to UE implementation | |
| Company: Apple | | Use case of the scheme: not well justified as mentioned by couple of companies. Do not support | | | |
| Any Restriction to apply the scheme: | | | |
| Any prerequisite to apply the scheme: | | | |
| Performance gain | | SNR gain: | |
| PAPR/CM gain: | |
| Spec impact: | | | |
| Impact to receiver | | Receiver complexity: | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | |  | |
| Company: Intel | Use case of the scheme: contiguous repetition is helpful for PUCCH coverage enhancement so as to allow PUCCH to occupy the uplink/flexible symbols as much as possible. | | | |
| Any Restriction to apply the scheme: long PUCCH formats only and UCI payload size <= 11 bits | | | |
| Any prerequisite to apply the scheme: | | | |
| Performance gain | | SNR gain: | |
| PAPR/CM gain: | |
| Spec impact:  Separate starting symbol and length of symbols for each slot during repetition can be configured by higher layers for a PUCCH resource. Cancellation of nominal PUCCH due to collision with invalid DL symbols/invalid symbols. | | | |
| Impact to receiver | | Receiver complexity: | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | |  | |
| Company: | Use case of the scheme: | | | |
| Any Restriction to apply the scheme: | | | |
| Any prerequisite to apply the scheme: | | | |
| Performance gain | | SNR gain: | |
| PAPR/CM gain: | |
| Spec impact: | | | |
| Impact to receiver | | Receiver complexity: | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | |  | |
|  |  | |  | |

## (Explicit or implicit) Dynamic PUCCH repetition factor indication

Companies are welcomed to provide views in the following table to identify the pros. and cons. of this scheme.

Table 9: Comments on the “(Explicit or implicit) Dynamic PUCCH repetition factor indication”

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Company:  Qualcomm | | Use case of the scheme: Currently PUCCH repetitions are tied to formats and not resources. Flexibility to dynamically indicate PUCCH repetition factor is useful in scenarios where the PUCCH payload needs additional protection/reliability. FR2 beam switching operations are one example. | | | |
| Any Restriction to apply the scheme: | | | |
| Any prerequisite to apply the scheme: | | | |
| Performance gain | | SNR gain: | |
| PAPR/CM gain: | |
| Spec impact: Need to introduce new signaling mechanism. Can be explicit (for e.g., via DCI) or implicit. | | | |
| Impact to receiver | | Receiver complexity: minimal | |
| Receiver sensitivity to time/frequency error: Same as NR PUCCH | |
| Impact to UE implementation | | minimal | |
| Company:  CATT | | Use case of the scheme: Alleviate the collision between PUCCH and other uplink channels. Reduce the overall overhead of PUCCH transmission. | | | |
| Any Restriction to apply the scheme: None | | | |
| Any prerequisite to apply the scheme: | | | |
| Performance gain | | SNR gain: | |
| PAPR gain: | |
| Spec impact: Specify how to indicate the repetition number, implicitly or explicitly. | | | |
| Impact to receiver | | Receiver complexity: None | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | | None | |
| Company:  Panasonic | | Use case of the scheme: In Rel.15, the number of PUCCH repetitions is semi-statically configured. The UCI payload size may be changed dynamically based on the DL data size and/or resource availability. Dynamic indication may reduce the redundant repetitions. | | | |
| Any Restriction to apply the scheme: | | | |
| Any prerequisite to apply the scheme: | | | |
| Performance gain | | SNR gain: | |
| PAPR/CM gain: | |
| Spec impact: How to indicate the number of repetitions dynamically should be specified. | | | |
| Impact to receiver | | Receiver complexity: | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | |  | |
| ZTE | | Use case of the scheme: Can be adaptive to variation of channel conditions, e.g., O2O case with relatively high UE speed. This could ensure the reliability or improve system efficiency. | | | |
| Any Restriction to apply the scheme: | | | |
| Any prerequisite to apply the scheme: | | | |
| Performance gain | | In our simulation, the signal power is set to an SNR of -12.8dB, which is the required SNR for the case with 11bits UCI and 4 repetitions. The simulation is to get the distribution of instantaneous received SNR at certain RBs and to see the percentage of instantaneous received SNR higher/lower than the required SNR for 4 repetitions. We find that the instantaneous received SNR is higher than the required SNR of 2 repetitions for more than 70% samples. In such cases, it can be indicated to 2 repetitions instead, which improves the system efficiency. Also, the instantaneous received SNR is lower than the required SNR of 4 repetitions for about 10% samples. In such cases, 8 repetitions should be indicated to ensure the reliability. | |
| PAPR/CM gain: | |
| Spec impact: Dynamic repetition indication. | | | |
| Impact to receiver | | Receiver complexity: | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | | Very small. | |
| Company:  Sharp | | Use case of the scheme: TDD | | | |
| Any Restriction to apply the scheme: | | | |
| Any prerequisite to apply the scheme: | | | |
| Performance gain | | SNR gain: | |
| PAPR/CM gain: | |
| Spec impact: Signalling of repetition number | | | |
| Impact to receiver | | Receiver complexity: | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | | Dynamic change of repetition for a PUCCH format | |
| Company:  OPPO | | Use case of the scheme: PUCCH ack dynamic repetition, indicated by scheduling DCI. | | | |
| Any Restriction to apply the scheme: no | | | |
| Any prerequisite to apply the scheme: no | | | |
| Performance gain | | SNR gain: | |
| PAPR/CM gain: | |
| Spec impact: Very small, 1 additional bit filed in the DCI format. | | | |
| Impact to receiver | | Receiver complexity: | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | | Very small. | |
| Company:  vivo | | Use case of the scheme: Indication of the number of PUCCH repetition through PRI | | | |
| Any Restriction to apply the scheme: No | | | |
| Any prerequisite to apply the scheme: the number of PUCCH repetition is configured on PUCCH resource instead of configured on PUCCH format in Rel-15. | | | |
| Performance gain | | Performance gain | |
| PAPR/CM gain: | |
| Spec impact:  *PUCCH repetition number is configured on PUCCH resource instead of configured on PUCCH format;* | | | |
| Impact to receiver | | Impact to receiver | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | | Impact to UE implementation | |
| Company:  Apple | | Use case of the scheme: potentially improves system efficiency, although the gain in not clear | | | |
| Any Restriction to apply the scheme: | | | |
| Any prerequisite to apply the scheme: | | | |
| Performance gain | | Performance gain | |
| PAPR/CM gain: | |
| Spec impact: | | | |
| Impact to receiver | | Impact to receiver | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | | Impact to UE implementation | |
| Company:  Intel | Use case of the scheme: more flexible repetitions for PUCCH compared to existing mechanism where number of repetitions is configured per PUCCH format. | | | |
| Any Restriction to apply the scheme: long PUCCH format only | | | |
| Any prerequisite to apply the scheme: | | | |
| Performance gain | | SNR gain: | |
| PAPR/CM gain: | |
| Spec impact: number of repetitions is configured in each PUCCH resource. | | | |
| Impact to receiver | | Receiver complexity: | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | |  | |
| Company: | Use case of the scheme: | | | |
| Any Restriction to apply the scheme: | | | |
| Any prerequisite to apply the scheme: | | | |
| Performance gain | | SNR gain: | |
| PAPR/CM gain: | |
| Spec impact: | | | |
| Impact to receiver | | Receiver complexity: | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | |  | |

## DMRS bundling cross PUCCH repetitions

Table 10: Comments on the “DMRS bundling cross PUCCH repetitions”

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Company: Qualcomm | | Use case of the scheme: The following comment is made assuming the current PUCCH repetition framework. This scheme may potentially benefit a cell-edge UE configured with (a) long-format PUCCH (PF3) spanning all 14 symbols of a slot (b) with PUCCH repetitions enabled and (c) slot pattern that has multiple contiguous U slots. Given the sparsity of uplink resources in TDD systems, unclear if the above three conditions are likely to ever occur for a cell-edge UE. | | | |
| Any Restriction to apply the scheme: Phase coherence needs to be maintained across repetitions, so there can be no gaps in transmission, no change in RB allocation, and no change in power across repetitions. | | | |
| Any prerequisite to apply the scheme: PUCCH needs to be configured with repetitions. Requires slot pattern to have multiple contiguous U slots. | | | |
| Performance gain | | SNR gain: | |
| PAPR/CM gain: none | |
| Spec impact: Rules for maintaining phase coherence across slots needs to be specified. Spec needs to specify how UE-side events such as power and timing adjustments that occur at slot boundary need to be handled. Given the rather large impact on overall UE architecture, limits of how long phase coherence needs to be maintained need to be imposed. | | | |
| Impact to receiver | | Receiver complexity: receivers need to be designed to process DMRS across multiple slots/repetitions. Time-frequency domain interpolation algorithms need to be updated. | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | | Maintaining phase coherence across slots requires UE to alter how slot boundaries are handled. Events (timing or power adjustments for example) queued up for slot boundaries will need to be postponed or cancelled. | |
| Company:  CATT | | Use case of the scheme: Improve the accuracy of channel estimation when PUCCH repetition is configured and transmitted on consecutive symbols. | | | |
| Any Restriction to apply the scheme: Same frequency resource allocation, same power on consecutive repetitions, phase should be continuous, etc. | | | |
| Any prerequisite to apply the scheme: | | | |
| Performance gain | | SNR gain: | |
| PAPR gain: | |
| Spec impact: Small | | | |
| Impact to receiver | | Receiver complexity: gNB may needs to determine whether to handle the channel estimation based on the DMRS across the repetition or not. The efforts on channel estimation increases. | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | | minimal | |
| Company:  Panasonic | | Use case of the scheme: In poor channel conditions, the improvement of channel estimation performance is essential. | | | |
| Any Restriction to apply the scheme: To support cross-slot or cross-repetition channel estimation, phase continuity needs to be ensured. | | | |
| Any prerequisite to apply the scheme: | | | |
| Performance gain | | SNR gain: | |
| PAPR/CM gain: | |
| Spec impact: In what condition phase continuity can be kept should be clarified. | | | |
| Impact to receiver | | Receiver complexity: Receiver needs channel estimation process over multiple slots. | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | | The transmission power is not changed over the multiple slots. | |
| ZTE | | Use case of the scheme: Both TDD and FDD with consecutive UL slots for PUCCH repetition. | | | |
| Any Restriction to apply the scheme: Phase continuity should be kept | | | |
| Any prerequisite to apply the scheme: | | | |
| Performance gain | | SNR gain: 1dB | |
| PAPR/CM gain: | |
| Spec impact: Rules may be needed to maintain the phase continuity. | | | |
| Impact to receiver | | Receiver complexity: gNB needs to perform cross-slot channel estimation. | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | | Keep phase continuity for multiple slots. | |
| Company:  Sharp | | Use case of the scheme: TDD and FDD | | | |
| Any Restriction to apply the scheme: Power consistency and phase continuity should be preserved. Same frequency position of DMRS. | | | |
| Any prerequisite to apply the scheme: | | | |
| Performance gain | | SNR gain: | |
| PAPR/CM gain: | |
| Spec impact: Specify duration for power consistency and phase continuity | | | |
| Impact to receiver | | Receiver complexity: Channel estimator and buffer needs to be enhanced such that multiple inputs from DMRS samples in different slot/repetition needs to be combined | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | | OFDM signal generation to preserve power consistency and phase continuity | |
| Company:  OPPO | | Use case of the scheme: Any existing PUCCH format with repetition. | | | |
| Any Restriction to apply the scheme: | | | |
| Any prerequisite to apply the scheme: PUCCH repetition with same frequency location of in different slots. | | | |
| Performance gain | | SNR gain: | |
| PAPR/CM gain: | |
| Spec impact: Enhanced Hopping pattern over the existing hopping schemes. | | | |
| Impact to receiver | | Receiver complexity: | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | | Small. | |
| Company:  LG | | Use case of the scheme: when the channel estimation of repeated PUCCH degrades due to the low SNR, it can be applied to improve channel estimation performance. | | | |
| Any Restriction to apply the scheme: the same frequency resource should be maintained during the bundled slot. | | | |
| Any prerequisite to apply the scheme: | | | |
| Performance gain | | SNR gain: | |
| PAPR/CM gain: | |
| Spec impact: it should be tied to inter-slot frequency hopping | | | |
| Impact to receiver | | Receiver complexity: | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | |  | |
| Company:  vivo | | Use case of the scheme: For long PUCCH with 14 symbols and repeated on consecutive slots. | | | |
| Any Restriction to apply the scheme: consecutive PUCCH transmission | | | |
| Any prerequisite to apply the scheme: UE need to guarantee coherency among the PUCCH repetitions. | | | |
| Performance gain | | Performance gain | |
| PAPR/CM gain: | |
| Spec impact:   * *UE need to keep the same Tx power across PUCCH repetitions if DMRS bundling is configured;* * *The time domain granularity should be defined for DMRS bundling;* * *Potential UE behavior needs to be defined if the coherency of PUCCH repetition is impacted by other procedures, e.g. simultaneous transmission if configured with CA.* | | | |
| Impact to receiver | | Impact to receiver | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | | Impact to UE implementation | |
| Company:  Apple | | Use case of the scheme: Technically enhances the coverage once repetition is performed. If the feature is supported in PUSCH, no reason it is not discussed/supported for PUCCH. | | | |
| Any Restriction to apply the scheme: consecutive PUCCH transmission | | | |
| Any prerequisite to apply the scheme: | | | |
| Performance gain | | Performance gain | |
| PAPR/CM gain: | |
| Spec impact: | | | |
| Impact to receiver | | Impact to receiver | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | | Impact to UE implementation | |
| Company:  Intel | Use case of the scheme: for coverage limited scenario, channel estimation is typically a bottleneck in terms of link level performance. It is important to improve channel estimation performance so as to enhance coverage. | | | |
| Any Restriction to apply the scheme: phase coherence for PUCCH repetition. | | | |
| Any prerequisite to apply the scheme: | | | |
| Performance gain | | SNR gain: 1.2dB compared to without cross-slot channel estimation. Further, when inter-slot frequency hopping with inter-slot bundling is employed, additional ~1.6dB performance gain can be achieved. | |
| PAPR/CM gain: | |
| Spec impact: Same Tx power and inter-slot frequency hopping with inter-slot bundling during PUCCH repetition. | | | |
| Impact to receiver | | Receiver complexity: | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | |  | |
| Company: | Use case of the scheme: | | | |
| Any Restriction to apply the scheme: | | | |
| Any prerequisite to apply the scheme: | | | |
| Performance gain | | SNR gain: | |
| PAPR/CM gain: | |
| Spec impact: | | | |
| Impact to receiver | | Receiver complexity: | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | |  | |

## Other schemes

Table 11: Comments on the “Other schemes ~~DMRS bundling cross PUCCH repetitions~~”

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Company:  CATT | | Scheme:  One-antenna port pre-coder cycling | Use case of the scheme: a universal solution to improve transmission performance | | | |
| Any Restriction to apply the scheme: At least two physical Tx is needed at UE side | | | |
| Any prerequisite to apply the scheme: | | | |
| Performance gain | | SNR gain: at least 1 dB | |
| PAPR gain: | |
| Spec impact: totally transparent and minimal specification impacts | | | |
| Impact to receiver | | Receiver complexity: Same as the current PUCCH receptition | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | | Minimal. The only thing UE needs to do is to scramble the bit sequence with a coder before transmit it on the physical Tx. | |
| Company: NTT DOCOMO | | Scheme: Repetition for PUCCH short formats | Use case of the scheme: PUCCH short formats are selected for FR2 with considering practical NW operation of using large number of BS antenna beams. And enhancement of short PUCCH format may avoid the complexity (e.g. different PUCCH formats for different antenna beams.) for the NW configuration and implementation. | | | |
| Any Restriction to apply the scheme: None | | | |
| Any prerequisite to apply the scheme: None | | | |
| Performance gain | | SNR gain: 1.5 dB for PF2 | |
| PAPR/CM gain: | |
| Spec impact: | | | |
| Impact to receiver | | Receiver complexity: None, since repetition for PUCCH format 1/3/4 is already supported. | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | | None, since repetition for PUCCH format 1/3/4 is already supported. | |
| Company: Samsung | Scheme: Introduce an offset value to ∆\_(F\_PUCCH ) (F) for SR and CSI report | | | Use case of the scheme: Allow the network to separately control the BLER targets for UCI types when multiplexing is in a PUCCH  Decouple target BLERs for different UCI types in PUCCH (they are decoupled in LTE or in the PUSCH). | | |
| Any Restriction to apply the scheme: | | |
| Any prerequisite to apply the scheme: | | |
| Performance gain | | SNR gain: |
| PAPR gain: |
| Spec impact: RRC specifications to introduce corresponding RRC parameters. RAN1 specifications are practically unchanged - only impact is to add the offset to the values of *deltaF-PUCCH-f0*, …, *deltaF-PUCCH-f4* and to allow different number of repetitions for different UCI types. | | |
| Impact to receiver | | Receiver complexity: |
| Receiver sensitivity to time/frequency error: |
| Impact to UE implementation | |  |
| Company: Samsung | | Scheme: Introduce PHR for PUCCH | Use case of the scheme: NR does not currently support PHR for PUCCH. Not always possible to derive PHR for PUCCH from PHR for PUSCH (which is supported). | | | |
| Any Restriction to apply the scheme: | | | |
| Any prerequisite to apply the scheme: | | | |
| Performance gain | | SNR gain: | |
| PAPR gain: | |
| Spec impact: Duplicate PUSCH PHR description to define PUCCH PHR (exchange PUSCH parameters with PUCCH parameters). Practically no RAN1 specification impact. MAC specifications already have a placeholder and can re-use the LTE mechanism for Type2-PHR (although Type-2 PHR in NR would not be for simultaneous PUCCH and PUSCH transmissions on the PCell). | | | |
| Impact to receiver | | Receiver complexity: | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | |  | |
| Company:  IITH, IITM, CEWIT, Reliance Jio, Tejas Networks | | Scheme: Power boosting for pi/2 BPSK | Use case of the scheme: Provides additional transmit power and directly enhances coverage | | | |
| Any Restriction to apply the scheme: | | | |
| Any prerequisite to apply the scheme: | | | |
| Performance gain | | SNR gain: | |
| PAPR/CM gain: | |
| Spec impact: 26 dBm solution already existing in the spec. Have to get RAN4 inputs on the possibility of further boosting. The boosting will be a function of UL duty cycle. Some indication for the same will be introduced. | | | |
| Impact to receiver | | Receiver complexity: | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | |  | |
| Company:  CMCC | | Scheme: PUCCH repetition with non-consecutive uplink slots | Use case of the scheme: solve the PUSCH transmission and long PUCCH repetition conflict issue in the uplink slot limited situation such as 7D1S2U. | | | |
| Any Restriction to apply the scheme: | | | |
| Any prerequisite to apply the scheme: | | | |
| Performance gain | | SNR gain: | |
| PAPR/CM gain: | |
| Spec impact: new repetition pattern for PUCCH | | | |
| Impact to receiver | | Receiver complexity: | |
| Receiver sensitivity to time/frequency error: | |
| Impact to UE implementation | |  | |
|  | |  |  | |  | |

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