**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 : 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 details not reported yet. |
| Intel | -1.0 ~ 0.2 dB SNR gain | 3/11 bits UCI, w/ DTX detection, 1% FA, 1% ACK miss, NACK->ACK error =?  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  Receiver details not reported yet. |

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 : 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 : 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 : 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 : Comments to the FL proposal

|  |  |
| --- | --- |
| Company | Comments |
|  |  |

# 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 : 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. |
| 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 : 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:  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: | 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 : 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 |  |
| 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 : 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. |
| 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 : Comments on the “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: | Scheme: | 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 |  |

# References

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