**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

# 1 Introduction

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

# 2 Summary of study on prioritized schemes

## 2.0 DTX detection for HARQ-ACK

**Necessity of DTX detection**

In the email discussion, 4 companies expressed the view that DTX detection is important for PUCCH carrying HARQ-ACK. One company express the view that DTX detection is not important for HARQ-ACK with medium/large payload size due to the rarity of DTX in this case.

**Previous agreement** (made in RAN1 101e)

* For link level simulation, adopt the following table for PUCCH for FR1.

|  |  |
| --- | --- |
| Parameters | Values |
| PUCCH format type | Format 1, 2bits UCI.Format 3, [4bits (3 bits A/N + 1 bit SR)]/11/22 bits UCI |
| BLER for PUCCH | For PUCCH format 1: DTX to ACK probability: 1%. NACK to ACK probability: 0.1%.ACK missed detection probability: 1%.For PUCCH format 3: BLER for Ack/Nack, SR: 1%FFS: BLER for CSI (10% or 1%) |

**RAN4 requirement**

According to RAN4 requitements in Section 8.3.1.2 in TS 38.104, The DTX to ACK probability shall not exceed 1% for all PUCCH formats carrying ACK/NACK bits.

According to RAN 4 requirements in Section 8.3.3.2 in TS 38.104, The ACK missed detection probability shall not exceed 1% at the SNR given in table 8.3.3.2.2-1 and in table 8.3.3.2.2-2.

According to RAN 4 requirements in Section 8.3.3.1 in TS 38.104, The NACK to ACK probability shall not exceed 0.1% at the SNR given in table 8.3.3.1.2-1 and table 8.3.3.1.2-2.

**Submitted simulation results with DTX detection**

For DMRS-less PUCCH:

* With 2 bits UCI in PUCCH format 1, 3 companies submitted simulation results with DTX detection (with requirements of 1% FA, 1% ACK miss, 0.1% NACK->ACK error)
* With 3 bits UCI in PUCCH format 1, 1 company submitted simulation results with DTX detection (with requirements of 1% FA, 1% BLER, without showing 0.1% NACK->ACK and 1% ACK miss performance)
* With 6 bits UCI in PUCCH format 1, 1 company submitted simulation results with DTX detection (with requirements of 1% FA, 1% BLER, without showing 0.1% NACK->ACK and 1% ACK miss performance)
* With 11 bits UCI in PUCCH format 1, 1 company submitted simulation results with DTX detection (with requirements of 1% FA, 1% BLER, without showing 0.1% NACK->ACK and 1% ACK miss performance)

For other three prioritized PUCCH coverage enhancement scheme, i.e., type B PUCCH repetition, dynamic PUCCH repetition factor indication, DMRS bundling cross PUCCH repetition, no company submitted simulation results with DTX detection.

By the way, for PUCCH coverage baseline study performed in 8.8.1.1 and 8.8.1.2, no company submitted PUCCH format 3 simulation results with DTX detection.

In summary, the status of DTX related study can be summarized as following

* Except for the DMRS-less PUCCH, no simulation results with DTX was submitted for other PUCCH coverage enhancement schemes.
* In the study of DMRS-less PUCCH performance
	+ For 2 bits UCI, the performance of FA, ACK miss, and NACK to ACK error were studied.
	+ For more than 2 bits UCI, only the performance of FA and BLER were studied. The performance of ACK miss and NACK to ACK error were not studied.

**Proposal 1: In addition to the results already submitted to RAN1 103e, for any PUCCH coverage enhancement scheme especially the four prioritized schemes, companies are encouraged to submit more simulation results by [11/10/2020] with DTX detection performed at receiver. Both results with and without DTX detection will be captured in the TR.**

* **For PUCCH with HARQ-ACK payload, the results with DTX detection should show performance with the following requirements: 1% DTX to ACK error rate, 1% ACK miss detection error rate, and 0.1% NACK to ACK error rate.**

Comments to the above FL proposal

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

## 2.1 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 DMRS-less PUCCH

|  |  |  |
| --- | --- | --- |
| Company | Observed performance gain  | Key simulation assumptions |
| ZTE | 2 ~ 3 dB SNR gain | **Scenario 5: 11 bits UCI,** w/o DTX detection, 1% BLERReceiver for Rel-15/16 PUCCH: ML coherent receiverReceiver for sequence based PUCCH: ML noncoherent sequence detector |
| Intel | -1.0 ~ 0.2 dB SNR gain | **Scenario 2: 3 bits UCI**, w/ DTX detection, 1% FA, 1% BLER **Scenario 5: 11 bits UCI**, w/ DTX detection, 1% FA, 1% BLER Receiver for Rel-15/16 PUCCH: ML coherent receiverReceiver for sequence based PUCCH: ML noncoherent sequence detector/correlator |
| Qualcomm | 3 ~ 4 dB SNR gain3.5dB PAPR gain w/ QPSK0.5dB PAPR gain w/ Pi/2 BPSK | **Scenario 1: 2 bits UCI**, w/ DTX detection, 1% FA, 1% ACK miss, 0.1% NACK->ACK error **Scenario 3: 4 bits UCI,** w/o DTX detection, 1% BLER**Scenario 5: 11 bits UCI**, w/o DTX detection, 1% BLER**Scenario 5: 11 bits UCI**, w/ DTX detection, 1% FA, 1% BLERReceiver for Rel-15/16 PUCCH: ML coherent receiverReceiver for sequence based PUCCH: ML noncoherent receiver (correlator with 2D-FFT or fast Hadamard transform)  |
| Sharp | 3 dB | **Scenario 3: 4 bits UCI,** w/o DTX detection, 1% BLERReceiver for Rel-15/16 PUCCH: MMSE channel estimation (with genie Doppler and delay spread) + ML coherent detectionReceiver for sequence based PUCCH: ML noncoherent sequence detector/correlator |
| CMCC | 1 ~ 2.7dB | **Scenario 5: 11 bits UCI**, w/o DTX detection, 1% BLERReceiver for Rel-15/16 PUCCH: ML coherent receiverReceiver for sequence based PUCCH: ML noncoherent sequence detector/correlator |
| vivo |  0.3 ~ 0.5dB | **Scenario 4: 6 bits UCI**, w/ DTX detection, 1% FA, 1% BLERReceiver for Rel-15/16 PUCCH: ML noncoherent detectorReceiver for sequence based PUCCH: ML noncoherent sequence detector/correlator |
| Ericsson | 0 ~ 0.2dB | **Scenario 5: 11 bits UCI**, w/o DTX detection, 1% BLERReceiver for Rel-15/16 PUCCH: conventional and ML noncoherent receiverReceiver for sequence based PUCCH: ML noncoherent receiver |
| EURECOM | Coding gain: 1.5 ~ 2.1dB 4.8 dB PAPR gain over DFT-S-OFDM with π/2-BPSK6.3 dB PAPR gain over DFT-S-OFDM with QPSK  | **Scenario 3: 4 bits UCI**, w/o DTX detection, 1% BLER**Scenario 5: 11 bits UCI**, w/o DTX detection, 1% BLER**Scenario 6: 22 bits UCI,** w/o DTX detection, 1% BLERReceiver for Rel-15/16 PUCCH: advanced receivers for <=11 bits(non-coherent ML), conventional receiver for 22 bits (LS channel esimtation + MMSE/MRC)Receiver for sequence based PUCCH: ML noncoherent sequence detector/correlator for 4/11 bit case; non-coherent LLR unit adapted to 3GPP polar code for 22-bit case. Also simulated low-complexity receiver for 11-bit UCI case. |
| Huawei, HiSi | 3 ~ 4dB4.5dB (PAPR gain) | **Scenario 1: 2 bits UCI**, w/ DTX detection, 1% FA, 1% ACK miss, 0.1% NACK->ACK error **Scenario 5: 11 bits UCI**, w/o DTX detection, 1% BLERReceiver for Rel-15/16 PUCCH: 2D-Wiener filter based channel estimation + MMSE equalizationReceiver for sequence based PUCCH: CHIRRUP algorithm based sequence detection |
| OPPO | ~3dB | **Scenario 1: 2 bits UCI**, w/ DTX detection, 1% FA, 1% ACK miss, 0.1% NACK->ACK error. Receiver for Rel-15/16 PUCCH: LMMSE-IRC receiver. Receiver for sequence based PUCCH: ML correlation. |

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]

Based on the input from companies in Section 4.1, the following proposal is made.

**Proposal 2: For DMRS-less PUCCH, capture the following in the TR**

**Use case:** enhance coverage of PUCCH with small and medium UCI size

**Restriction of the scheme:** up to X UCI bits where X is FFS

**Prerequisite of the scheme:** None

**Performance gain:** captured in Table 1

**Spec impact:**

* A new PUCCH format needs to be specified, including the power control of the new PUCCH format. The new PUCCH format is an addition to existing PUCCH formats.
* if reusing Rel-15/16 CGS/ZC/Gold/m-sequence, no new sequences need to be specified. If new sequences or ~~new scrambling procedure with~~ sequences based on modification of NR Rel-15/16 UCI encoding scheme are adopted, the new sequences or the modification of NR Rel-15/16 UCI encoding scheme ~~new scrambling procedure~~ need to be specified.
* UCI to sequence mapping and Sequence to RE mapping need to be specified
* UCI size (X) needs to be specified
* [New RAN4 MPR requirement needs to be defined, if new sequences other than Rel-15/16 CGS/ZC/Gold/m-sequences are adopted]
* [CSI and HARQ-ACK multiplexing for this new PUCCH format need to be specified]

**Impact to receiver:**

* Need to implement a ML non-coherent sequence detector/correlator for the new PUCCH format.
* No need to implement channel and noise estimation in the receiver for the new PUCCH format
* Receiver implementation for the new PUCCH format ~~can leverage from~~ is an extension of the PUCCH format 0 receiver with similarity that both are noncoherent sequence detectors, while the new receiver needs to perform correlation over a larger sequence pool.
* The complexity of the ML non-coherent sequence detection/correlation ~~may~~ increase ~~the receiver complexity~~ with larger UCI size.
* Computation efficient implementations are available with certain choice of sequences to reduce receiver complexity. Depends on UCI size, selected sequences, and implementation of ML noncoherent and conventional coherent receiver, ML non-coherent sequence detector ~~can have smaller~~ may have larger or smaller complexity than conventional NR PUCCH coherent receiver.
* [Receiver sensitivity to time/frequency error: ML non-coherent sequence detector is more robust to timing and frequency than conventional NR PUCCH coherent receiver]
* [Similar to PUCCH format 0, the new PUCCH format does not have DMRS for interference suppression and tracking loops]

**Impact to UE implementation**

* ~~Simple~~ UE ~~Tx implementation without~~ does not need to implement channel encoder for the new PUCCH format
* UE implementation effort for this new PUCCH format can be reduced by reusing Rel-15/16 CGS/ZC/Gold/m-sequences, comparing with new PUCCH format based on introduced new sequences or modification of Rel-15/16 UCI encoding

 **[Impact to system]**

* [FFS the impact to system]

Comments to the above FL proposal

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| --- | --- |
| Company | Comments |
| Ericsson | From a gNB receiver perspective, the UCI encoding scheme is new, so I think it is correct to call it a new encoding scheme.Our comments on the difficultly to suppress interference due to lack of DMRS and the inability to use DMRS for channel tracking need to be taken into account in ‘impact to receiver’. Suggest: * Interference suppression may be infeasible due to lack of DMRS.
* gNB is unable to use DMRS for channel tracking

How the gNB does DTX detection will also change with this approach, so that should be added as an impact to the receiver. |
| Qualcomm | Some comments on DMRS-less PUCCH based on the discussion in the FL summary and in the email discussions:1. It is not clear to us what “disables existing coding scheme” means or even why this is problematic. We have conceded that sequence-based design, if agreed, would be a new format. With a new format certain changes, restrictions, etc are to be expected. There is no free lunch. Note that this format is in addition to the existing formats, so if a current scheme utilizes a certain encoding/decoding scheme, it can continue to do so.
2. From a performance evaluation standpoint, for baseline coverage characterization we all seemed fine with using BLER targets (i.e., 1%, please see R1-101e agreements) to characterize coverage. But now, when it comes to enhancements, additional targets are being proposed. We clearly can’t have one goal post for baseline and another for enhancements. We also cannot pick and choose the constraints we wish to impose. We would like to know first if we should redo our baseline coverage characterization based on any new constraints. Until an answer to this question is arrived at, we do not wish to capture any arguments in this regard in the TR.
3. We also do not wish to make broad statements that control channel changes have a broad impact on system design. Barring exact specifics, preferably backed by some evidence, please leave such overly broad statements out of the TR. Regarding the lack of DMRS, we note that PF0 also doesn’t have DMRS, and we hope that the gNB design philosophy adopted for PF0 can be repurposed.
4. Regarding UCI payload size, until a design is finalized, we will not be able to identify this range accurately. Rather than pursuing preciseness, it will be good to have some room to further define this in the WI phase, assuming we pursue this enhancement.
5. Regarding “performance gain” please see earlier comment. Request clarification on baseline coverage characterization first. We don’t want to give the impression that RAN1 did not sufficiently study the performance of this enhancement. Many companies are still in the process of aligning their simulation results and we don’t want to make any premature statements in this regard.
6. Regarding alignment across companies, given the diverse set of results, can we urge companies to use one of the agreed baseline PUCCH configurations for ease of comparison (for e.g., payloads 4/11/22 bits, PF3, 1RB allocation etc). We have noticed that the results can vary depending on the choice of sequence, so it helps to align on the configuration first, before going deeper on sequence design. It will be great if we can align on BLER performance first, before moving to other considerations (if necessary and agreed upon).
7. Regarding receiver/detection complexity, our analysis indicates that the overall computations for the non-coherent approach can be fewer than that required for coherent detection of NR PUCCH. This is however dependent on payload size. We therefore do not wish to declare that this method necessarily results in an increase in receiver/detection complexity. We are happy to see any complexity analysis that indicates otherwise. This complexity trade-off may influence our decision on the UCI payload size limits we place on this design.
8. PF0 sets a clear precedent on how gNBs can implements receivers for sequence detection. While the implementation may not be directly reusable, it does offer a blueprint on how a gNB can function under such a scheme. We wish to see it recorded that this scheme is in effect an extension of the principles used in PF0, and some of the design principles can be reused.
 |
| Samsung | Some of the comments captured in the FL proposal are not meaningful. For example, the “simple UE Tx implementation without channel encoder” is not meaningful as a Rel-15/16 UE already has such encoder (and it will remain present). For example, although the proposed DMRS-less PUCCH is in principle same as PUCCH format 0, it is not true that gNB/UE implementation can be reduced since existing ones for PUCCH format 0 cannot support the new PUCCH format. New transmitter/receiver blocks will be required.The system impact needs to also be considered. Given that the percentage of UEs requiring PUCCH coverage enhancements will be small, the overall system impact from possibly increasing a number of repetitions for a legacy format needs to be assessed in order to determine a benefit from introducing a new PUCCH format.  |
| Intel | * Regarding “use case”
	+ Depending on the simulation results presented so far, we suggest to modify the observations as “Some companies claimed that use case of DMRS-less PUCCH is to enhance coverage of PUCCH with small and medium UCI size. Some other companies claimed that there is no use case of DMRS-less PUCCH for coverage enhancement.”
* Reusing existing sequence
	+ We are not sure if the mentioned sequences of Rel-15/16 CGS/ZC/Gold/m-sequence can generate sufficient number of sequences to deliver the message of X bits. It should be removed or stated as observations from different companies.
* Regarding “Prerequisite of the scheme”,
	+ Similar the comment as above, we would like to consider long PUCCH format as Prerequisite of the scheme.
* Regarding the “impact to receiver”
	+ DTX detection for impact to receiver should be added as it is typical implementation not only for HARQ-ACK detection but for CSI on dropping rule and UCI piggybacking on PUSCH. With DMRS-less PUCCH scheme, it is clear that new DTX detection algorithm needs to be implemented.
	+ For receiver complexity, we share similar view as Nokia the email that this is highly dependent on specific implementation of current NR PUCCH receiver at base station. The claim that ML non-coherent sequence detection has smaller complexity than conventional PUCCH coherent receiver should not be accurate. For instance, with conventional receiver with coherent detection, Fast Hadamard Transform can be used for RM decoding. We need to conduct comprehensive study before we can make such a statement. We suggest to remove this statement.
	+ For “Receiver implementation for the new PUCCH format can leverage from PUCCH format 0 receiver”, we are not sure whether this is correct statement. In particular, when relatively large UCI payload size is considered, the receiver implementation is significantly different from that for PF0 (e.g. whether sequence is inserted in time or frequency domain). For instance, for UCI payload size of 11 bits, it is expected 2^11 correlator is needed to detect the correct sequence, which has huge difference compared to the receiver for PF0. We suggest to remove this statement or to state opinions from different companies.
		- On noise estimation, it must be implemented for DTX detection anyway.
		- On “[Receiver sensitivity to time/frequency error: ML non-coherent sequence detector is more robust to timing and frequency than conventional NR PUCCH coherent receiver]”, this statement is not true given that coherent detection is more robust in residual timing error (i.e. phase ramping in frequency domain) which is being compensated in channel estimation/equalization. Rather, non-coherent detection is generally vulnerable to residual time/frequency error since we need partial correlator or differential correlator in frequency domain or multiple hypothesis in time domain. Therefore, this should be removed.
* Regarding impact to UE implementation
	+ For “Simple UE Tx implementation without channel encoder”, we are not sure whether this is correct statement as this is also highly dependent on UE implementation. For current RM code, RM encoded symbols are also another type of sequence.
	+ For “UE implementation effort can be reduced by reusing Rel-15/16 CGS/ZC/Gold/m-sequences”, we are not sure what is the baseline to compare with. Compared to existing PUCCH scheme, implementation effort is increased.

Therefore, we suggest the following modifications from FL summary:**Proposal 1: For DMRS-less PUCCH, capture the following in the TR**RAN1 discussed option of DMRS-less PUCCH for coverage enhancement with the following observations.**Use case:** Some companies claimed that use case of DMRS-less PUCCH is to enhance coverage of PUCCH with small and medium UCI size. Some other companies claimed that there is no use case of DMRS-less PUCCH for coverage enhancement.**Restriction of the scheme:** Some companies proposed to consider up to X UCI bits for further discussion on DMRS-less PUCCH where X is FFS.**Prerequisite of the scheme:** long PUCCH format as prerequisite for further discussion on DMRS-less PUCCH.**Performance gain:** Different companies have observed performance gain/loss as captured in Table 1.**Spec impact if DMRS-less PUCCH is introduced:** * A new PUCCH format needs to be specified, including the power control of the new PUCCH format.
* There are proposals to consider to reuse Rel-15/16 CGS/ZC/Gold/m-sequence. If new sequences or new scrambling procedure with NR Rel-15/16 UCI encoding scheme are adopted in order to increase the information bits, the new sequences or the new scrambling procedure need to be specified. On the other hand, there is also an observation that, if we reuse existing RM coding table, there is no need to introduce any other new sequence.
* Sequence to RE mapping need to be specified
* Upper bound of supported UCI size (X) needs to be specified
* [New RAN4 MPR requirement needs to be defined, if new sequences other than Rel-15/16 CGS/ZC/Gold/m-sequences are adopted]

**Impact to receiver if DMRS-less PUCCH is introduced:** * Channel estimation block can be avoided in PUCCH receiver. There is still need to implement noise/interference estimation for DTX PUCCH detection.
* Need to implement a new non-coherent sequence detector/correlator.
* ML non-coherent sequence detection/correlation may increase the receiver complexity since the detector/correlator cannot leverage FHT (Fast Hadamard Transform) from existing Rel-15 RM coding.
* There are some opinion that computation efficient implementations are available with certain choice of sequences to reduce receiver complexity.
* There is some opinion that receiver implementation for the new PUCCH format can leverage from PUCCH format 0 receiver depending on the sequence types.

**Impact to UE implementation*** There is a claim that simple UE Tx implementation can be achieved without channel encoder. On the other hand, there is another claim that existing Rel-15 RM encoder is nothing but another type of sequence where RM decoder is also nothing but ML decoding that can support both coherent and non-coherent detection.
* There is an opinion that UE Tx implementation effort can be reduced by reusing Rel-15/16 CGS/ZC/Gold/m-sequences for DMRS-less PUCCH. There is also another opinion that there is almost no UE Tx implementation impact by reusing existing Rel-15 RM coded sequence.
 |
| LG | It is notable that “sequence to RE mapping” and new PUCCH format is necessary only if new sequence or new scrambling procedure are adopted. Therefore, we suggest the following modification in first to third bullets of spec impact.Original)* A new PUCCH format needs to be specified, including the power control of the new PUCCH format.
* if reusing Rel-15/16 CGS/ZC/Gold/m-sequence, no new sequences need to be specified. If new sequences or new scrambling procedure with NR Rel-15/16 UCI encoding scheme are adopted, the new sequences or the new scrambling procedure need to be specified.
* Sequence to RE mapping need to be specified

Suggesting modification)* If reusing Rel-15/16 Rel-15/16 CGS/ZC/Gold/m-sequence, no new sequences need to be specified. As a consequences, no new PUCCH format and no sequence to RE mapping need to be specified.
* If new sequence or new scrambling procedure with NR Rel-15/16 UCI encoding scheme are adopted, a new sequences or the new scrambling procedure need to be specified. As a consequence, new PUCCH format and sequence to RE mapping need to be specified.
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| ZTE | We are generally fine with the proposal, with the following minor changes:* Adding ‘UCI to sequence mapping needs to be specified’ as one additional spec impact.
* Adding ‘long PUCCH format’ as the prerequisite of the scheme.

We agree that, no matter whether new sequences would be introduced or not, a new PUCCH format should be defined. It includes both UCI to sequence mapping and sequence to RE mapping. Regarding “use case”, we don’t think we need to add ‘some companies claimed that ...’. The proposed DMRS-less is intended for PUCCH carrying small and medium UCI size. If companies worried about the performance gain/spec impact/complexity, these worries could be added in corresponding performance gain/spec impact/complexity parts, while these aspects seem have already been well captured in the proposal. |
| Vivo | For spec impacts brought by sequence based PUCCH, as we mentioned in the 1st round, there would be some other specification impacts, which are not included in the current proposal.* 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. It is necessary to clarify what is coding rate of a sequence based PUCCH if UCI multiplexing on this new PUCCH format is supported.
* PUCCH format specific power adjustment component  for the new PUCCH format, should be defined in TS 38.213.
 |
| Nokia/NSB | We copy-paste here snippets of what we sent to the Reflector and was also referred to by other companies. Minor additional comments are also added and typos are corrected.**Restriction of the scheme:** It is important to have a numerical value, or a range, in the TR instead of a placeholder. This should capture a correct value (in the sense what is assumed or used in the evaluations and complexity discussions) as generalizing observations listed in the following is not valid for an arbitrary value X. We are not sure **Performance gain:** This scheme would replace the channel coding chain; however it would still have the same functional role in the system. As such, as also mentioned by Ericsson, it should be considered and studied as if it were a coding scheme. In this regard, we are not talking about correcting errors, of course, but more about the impact that specific designs of the control channel have on the system behavior/performance, beyond just coverage evaluations. Additional details related to this specific concern are below.  **Impact to receiver:** * Efficient implementations of ML-detector were indeed studied and that should be captured in the TR. However, the current formulation of the bullet implies something stronger in our view, which would probably deserve a deeper discussion. As of now, we have not discussed this aspect, and we may very likely not do that due to lack of time. Additionally, the statement about conventional “NR PUCCH coherent receiver” is based on assumptions on gNB implementation which are hardly verifiable, clearly an implementation detail, and not agreed in RAN1 as baseline for this evaluation. Intel seems to share the same concern. While we are not completely sure about the proposed wording, we think their proposals could be used as a starting point to improve the bullet.
* It is stated that receiver implementation for the new PUCCH format can leverage from PUCCH format 0 receiver. Other companies already commented on this, and we agree with their comments. Furthermore, correlators for PUCCH format 0 only check a small set of combinations and do not scale-up when the payloads are increasing.  Therefore, we do not think it is correct to claim that a larger payload can leverage the same receiver, even if the non-coherent nature of the detection applies to both.
* As Intel mentioned, details on how well receiver can handle FAR/PMD when the threshold of the correlator when a 1-2 bit(s) UCI payload is received have not been studied (at least we have not found any result in this regard in the contributions submitted by companies to 8.8.2.2). We think this is very important point to consider, given that what we are discussing is not a “simple” coverage enhancement but a change to control channel which may have important impacts beyond coverage aspects (as also mentioned by Samsung). Indeed, as we know from coding discussions during Rel-15, error detection becomes a very important metric as UCI payloads get larger. This is also visible in 38.212, where it becomes more challenging to support the error detection based on the inbuild coding structure when payload sizes are increasing, and thus, additional CRC is added.
* Linked to the previous point, consider what current formats allow gNB to do, e.g., identifying when a decoded UCI payload is “wrong” or not by looking at CRC for instance, and what does not seem so trivial to achieve using a non-coherent PUCCH format with payload larger than 1 bit. Having a PUCCH format which does not help gNB understanding if a PUCCH is received but wrongly decoded may significantly impact aspects related to gNB operations as compared to what can be done with other formats, such as at least, but limited to:
* gNB’s downlink scheduler;
* gNB’s uplink scheduler;
* the performance of any downlink algorithm relying on the content of the UCI (e.g., beamforming).

Comments by Ericsson provide another example of consequences in this sense. |
| NTT DOCOMO | We are generally fine with the FL proposal. We don’t want to preclude PUCCH short format from the technique, since enhancement of PUCCH short format is also important for FR2 operation and NW configuration. |
| Qualcomm | Please find a few additional remarks:1. With regard to use case, we wish to second ZTE’s comment. If there are concerns they can be addressed in performance gain/spec impact/complexity parts.
2. We don’t want to restrict this and other enhancements to long format PUCCH alone. We prefer to address this at a later point, once link budget analysis is complete. There appears to be strong operator interest in seeing some enhancements targeted at short PUCCH and we would like to take this input into consideration.
3. As to Nokia and Ericsson’s comment on system impact, if there are quantitative means to study this impact, let us know, we can try to study them. If this is general commentary on what is impacted, then it is not clear how to address or take this into account. Pretty much every scheme proposed here has system impact --- type B repetitions, DMRS bundling, etc. Some of these schemes require rethinking the relevance of a slot boundary --- this in our view has profound implications for system design. We don’t see similar concerns being raised in those enhancements.
4. If system impact is a concern, we can draw a separate list of concerns that apply to each of the 4 schemes being studied with higher priority.
5. We want to highlight the rarity of DTX events when a PUCCH transmission is set to carry multiple HARQ-ACK/NACK bits. Assuming each bit in the UCI payload maps to a unique downlink grant, a DTX event is triggered when a UE misses all of its downlink grants. Given that PDCCH is assumed to have a reliability of 10^-2, with even 4 HARQ-ACK/NACK bits, this event occurs with probability 10^-8, assuming independence across grant receptions. Thus, an over-emphasis on DTX detection seems unwarranted and may not reflect the needs of a practical deployment.
6. Having said the above, we are okay to investigate the performance beyond BLER as a metric. In particular we would like to consider NACK->ACK rate as well as DTX->ACK into account. We can reuse the targets we assumed for Format 1. We would also like these new benchmarks to be applied to other enhancements as well. We request the FL to establish a common set of performance criteria that applies to all PUCCH enhancements.
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## 2.2 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]

Based on the input from companies in Section 4.2, the following proposal is made.

**Proposal 3: For PUSCH repetition type-B like PUCCH repetition, capture the following in the TR**

**Use case:** PUCCH type B repetition can reduce PUCCH latency and improve resource utilization efficiency. But its benefit to coverage enhancement is not clear. [The scheme may only be beneficial for short PUCCH repetition.]

**Restriction of the scheme:**

* Only applicable to UCI <=11 bits
* [Only applicable to actual PUCCH repetitions in a same PUCCH format]

**Prerequisite of the scheme:** None

**Performance gain:** Captured in Table 2

**Spec impact:**

* Nominal repetition, actual repetition, ~~and~~ segmentation for type B PUCCH repetition, and flexible time domain resource allocation in each slot need to be specified
* Procedure to handle postpone/cancel PUCCH repetitions (including interaction with dynamic SFI) needs to be specified
* [PUSCH type B repetition specification can be leveraged]
* Procedure to transmit actual repetition in DFT-S-OFDM waveform with 1/2/3 OFDM symbols needs to be specified, if 1/2/3 OFDM symbol actual type B PUCCH repetition is supported
	+ Potentially new DMRS patterns need to be specified
* Procedure and RAN4 requirements to handle different PUCCH formats (with potential switching between different waveforms of OFDM and DFT-S-OFDM) cross actual repetitions needs to be specified
* Power control for actual repetitions needs to be specified
* [CSI and HARQ-ACK multiplexing with type B PUCCH repetition need to be specified]

**Impact to receiver:**

* gNB needs to process more than one PUCCH repetitions in a slot
* gNB needs to combine multiple repetitions with different code rates/time length

**Impact to UE implementation**

* UE needs to implement PUCCH postponement/cancellation procedure
* UE needs to implement PUCCH repetitions with different code rates/time length
* UE needs to implement transmissions of more than one PUCCH repetitions in a slot

 **[Impact to system]**

* [FFS the impact to system]

Comments to the above FL proposal

|  |  |
| --- | --- |
| Company | Comments |
| Ericsson | Similar to FL comment, it would be good to clarify if this is only for short PUCCH repetition. Also, is this one scheme or many? That is, are all spec impacts required for all proposals? |
| Qualcomm | If repetitions across slot boundaries, then phase continuity issues come up. Prefer to take a cautious approach in this case, and seek RAN4 input first. |
| Samsung | The proposal for Type-B like PUCCH repetitions intends to leverage for PUCCH the Rel-16 support for PUSCH. Almost all aspects mentioned by the FL already exist for PUSCH Type B repetitions. The PUCCH format for different repetitions need not be different but, even if it is, that does not matter as decoding is based on soft bits and the gNB can receive any PUCCH format that has a corresponding configured PUCCH resource. Procedure to handle postpone/cancel PUCCH repetitions is already specified in Rel-15.Support is intended to be limited to below 12 bits (repetition coding or RM coding) – the impact on UE/gNB implementation relative to Type-B PUSCH repetitions is trivial. |
| Intel | * Regarding “use case”
	+ For “The scheme may only be beneficial for short PUCCH repetition.” We are not sure whether this is valid. Assuming special slot of 7 UL symbols and 14-symbol uplink slot, we can use this scheme to transmit 7-symbol long PUCCH with 3 repetitions, while existing PUCCH repetition scheme can only have 2 repetitions. It is clear that this is also beneficial for long PUCCH format. We suggest to remove this.
* Regarding “Prerequisite of the scheme”,
	+ Similar the comment as above, we would like to consider long PUCCH format as Prerequisite of the scheme at least for NR Coverage enhancement SI/WI.
* Regarding “spec impact”
	+ As mentioned in the first round of email discussion and also by other company, we also consider flexible time domain resource allocation in each slot for enhanced PUCCH repetition scheme, which can avoid the introduction of segmentation to some extent. We suggest to update the first sub-bullet as “Nominal repetition, actual repetition, and segmentation for PUCCH and flexible time domain resource allocation in each slot need to be specified
	+ For “Procedure to transmit actual repetition in DFT-S-OFDM waveform with 1/2/3 OFDM symbols needs to be specified – Potentially new DMRS patterns need to be specified”, we are not sure which company proposed this for spec impact. Does this mean we would need to introduce a new PUCCH format for DFT-s-OFDM waveform with 1/2/3 OFDM symbols, e.g., for PF0 and PF2? And we would like to introduce a new PUCCH format to cover 3 symbol PUCCH? We suggest to remove this.
 |

## 2.3 (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 Dynamic PUCCH repetition factor indication

|  |  |  |
| --- | --- | --- |
| 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.

Based on the input from companies in Section 4.3, the following proposal is made.

**Proposal 4: For dynamic PUCCH repetition factor indication, capture the following in the TR**

**Use case:** More flexible indication of PUCCH repetition factor to improve resource utilization efficiency. But its benefit to coverage enhancement is not clear.

**Restriction of the scheme:** None

**Prerequisite of the scheme:** None

**Performance gain:** captured in Table 3

**Spec impact:**

* a new PUCCH repetition signalling mechanism needs to be specified

**Impact to receiver: None**

**Impact to UE implementation:**

* Need implement transmissions of the PUCCH repetitions based on the dynamic indicator

 **[Impact to system]**

* [FFS the impact to system]

Comments to the above FL proposal

|  |  |
| --- | --- |
| Company | Comments |
| Ericsson | Regarding coverage vs. spectral efficiency: These two aspects are nearly indistinguishable. For example, we can use UL heavy TDD patterns to improve coverage, but we study only DL heavy TDD patterns in this study item. The reason is that we want the DL spectral efficiency. For dynamic PUCCH repetition, in a coverage scenario we may want say 8 repetitions, but an 8x constant increase in PUCCH overhead is not desirable, and dynamic control of repetition factor can solve this problem. Suggest for use case: ‘More flexible indication of PUCCH repetition factor to improve coverage while maintaining spectral efficiency’. |
| Samsung | Largely agree with the FL comments. Support for PUCCH repetitions in Rel-15 was imported from LTE Rel-8 that was designed for 1 HARQ-ACK bit. As a result, that support is broken for the purposes of NR.Regarding the impact on coverage, there isn’t any if the number of configured repetitions is always the maximum one corresponding to the maximum possible UCI payload that RAN1 will agree to support. But that is clearly a flawed design.Also, the number of repetitions should depend on the UCI and not be the same for all UCI types – a network does not always target a same reliability for HARQ-ACK/SR/CSI. |
| Intel | * Regarding “Prerequisite of the scheme”,
	+ Similar the comment as above, we would like to consider long PUCCH format as Prerequisite of the scheme at least for NR Coverage Enhancement SI/WI.
 |
| ZTE | We basically agree with Ericsson’s suggestion on the use case of this scheme. |

## 2.4 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 DMRS bundling cross PUCCH repetitions

|  |  |  |
| --- | --- | --- |
| 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.

Based on the input from companies in Section 4.4, the following proposal is made.

**Proposal 5: For DMRS bundling cross PUCCH repetitions, capture the following in the TR**

**Use case:** Improve channel estimation ~~with~~ for [back-to-back] PUCCH repetitions

**Restriction of the scheme:**

* Phase coherency cross PUCCH repetitions
* Same frequency resource allocation cross PUCCH repetitions
* Same power cross PUCCH repetitions

**Prerequisite of the scheme:** PUCCH repetition is enabled/configured, with multiple back-to-back repetitions

**Performance gain:** captured in Table 4

**Spec impact:**

* Restrictions to guarantee phase coherency cross repetitions need to be specified
* UE behaviour needs to be defined if the phase coherency of PUCCH repetition is impacted by other procedures
* DMRS bundling with inter-slot frequency hopping pattern enhancement need to be specified, if the frequency hopping enhancement is agreed.

**Impact to receiver:**

* New channel estimator needs to be implemented to process DMRS across multiple repetitions

**Impact to UE implementation**

* Same phase and transmission power need to be maintained cross PUCCH repetitions
* [Maintaining phase coherence across slots requires UE to alter how slot boundaries events (such as timing or power adjustments) are handled]

 **[Impact to system]**

* [FFS the impact to system]

**Proposal 6: For DMRS bundling cross PUCCH repetitions, send an LS to RAN4 to ask under what conditions UE can keep phase and power coherence cross PUCCH repetitions.**

Comments to the above FL proposal

|  |  |
| --- | --- |
| Company | Comments |
| Qualcomm | We think some input from RAN4 may be necessary due to the phase continuity issues across slot boundary. UE architecture is heavily designed around a slot-based state machine, so bundling poses challenges to this architecture. Also, there are power consumption considerations when developing UE RF architectures to support such features, so it is best to take a more cautious approach. |
| Intel | * Regarding “use case”
	+ We are not sure whether we need to restrict this to back to back repetition. Certainly, this needs input from RAN4. Suggest to remove this or at least put into square bracket for further check.
* Regarding spec impact
	+ We suggest to add “inter-slot frequency hopping with inter-slot bundling during PUCCH repetition.”, which is similar to PUSCH coverage enhancement. In our simulation results, when inter-slot frequency hopping with inter-slot bundling is employed, additional ~1.6dB performance gain can be achieved.
 |

## 2.5 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.  |
| Ericsson | Agree with FL that t/f error is relevant, especially to the DMRS bundling case.Agree with intel that DTX detection is a relevant matric. OK to send LS, but decisions at this meeting should not be contingent on receiving an LS reply. LSs may be helpful e.g. for early guidance in a WI stage. |
| LG | Agree with vivo and intel that additional performance metric can be reported if necessary. |

# 3 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 MIL5.0 dB LLS |

# 4 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.

## 4.1 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 “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 lengthWhile 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:InterDigital | Use case of the scheme: PUCCH payload between 2-22 bits in power-limited scenario |
| Any Restriction to apply the scheme: there will be a maximum payload |
| Any prerequisite to apply the scheme:  |
| Performance gain | SNR gain:  |
| PAPR/CM gain:  |
| Spec impact:  |
| Impact to receiver | Receiver complexity: No need for DMRS channel estimation. Need to implement sequence detection. However, it may be possible to limit complexity/reuse implementations by mapping to Zadoff-Chu sequences for smaller payloads, or by splitting larger payloads into smaller groups (each of which being mapped to a separate sequence). |
| Receiver sensitivity to time/frequency error:  |
| Impact to UE implementation | Limited impact. |
| Company: Nokia/NSB | Use case of the scheme: Even though the name of the scheme is referred to as ‘DMRS less PUCCH transmission’, the idea is to have a new format in which RM codes (3-11 bits) and, possibly Polar codes (12-22 bits depending on the range), are replaced by sequence-based PUCCH transmission. This implies a change of coding scheme, whose impact goes far beyond coverage enhancement, as argued below.  |
| Any Restriction to apply the scheme: Short block size channel coding was specified in Rel-15 and changes on that may have a significant impact on both UE and gNB implementation. Even if RAN1 captures details on this scheme in the TR, it would then be up to RAN to decide allowed changes to coding techniques in the WI discussion, as there could be other channel coding chain related proposals instead of sequence-based to improve the coverage performance in this short block range. |
| Any prerequisite to apply the scheme:  |
| Performance gain | SNR gain:  |
| PAPR/CM gain:  |
| Spec impact: All the PUCCH formats are built on top of assumption of payload sizes. For sequence-based ones, “repetition” and “simplex’ codes are applied (below 2 bits). If the sequence-based scheme is applied for larger payloads, it is not clear what background code shall be specified (compared to existing methods). |
| Impact to receiver | Receiver complexity: The sequence detection schemes, which would support same payload sizes with RM codes and/or polar codes, would have to be implemented in parallel with the existing PUCCH formats. In this regard, it is worth noting that sequence-based schemes would have to work together with existing methods, as they will still have to be used to support legacy UEs. Co-existence evaluations are also not done in this study to see the impact of this proposal on existing PUCCH formats detections. Once again, we should not ignore that a change of coding scheme is not just about coverage extension.Furthermore, it is unclear how the FAR/PMD and miss-detections are handled in this case, as existing implementation-based techniques on RM and polar codes cannot be used to handle error detection. A problem on error detection may arise in practice and no attention is being given to this aspect. Indeed, as far as existing evaluations go in this AI, RAN1 is not carrying out simulations considering FAR and PMD. Evaluation methodology has been designed to test coverage of the channel, not the impact of a coding scheme change. In this regard, it is important to add that FAR and miss-detection evaluations and capabilities were well observed and considered in existing codes (in Rel-15 discussions). For instance, sequence-based methods were not considered as suitable methods above 2 bits of UCI payload, also considering extra complexity associated with detecting larger sequences. |
| Receiver sensitivity to time/frequency error: The relationship between this aspect when comparing sequence-based schemes and existing methods is not clear.  |
| Impact to UE implementation | As implied previously, more impact is expected on gNB as two different chains have to be considered and guarantee of error detection is not clear. There may also be an additional burden on gNB when satisfying error detection requirements. On the other hand, it is not trivial in our view to say that the impacts at the UE would be more straightforward, as hardware components related to encoding get impacted. UE implementations have to support both legacy PUCCH formats and new PUCCH formats as well. |
| Company:Ericsson | Use case of the scheme: 3-11 bit UCI in format 3 |
| Any Restriction to apply the scheme: Difficult to suppress interference due to lack of DMRS; unable to use DMRS for channel tracking. |
| Any prerequisite to apply the scheme:  |
| Performance gain | SNR gain: 0 to 0.2 dB |
| PAPR gain: FFS. Note: In our understanding, PAPR generally overestimates gain. This is why cubic metric was developed (please see e.g. R1-060023) and should be used instead. |
| Spec impact: FFS. At least includes FEC design, channel structure, resource allocation |
| Impact to receiver | Receiver complexity: Additional receiver needed for DMRS payloads > 11 bits; may require multi-hypothesis detection, depending on FEC design; New DTX detection that is not based on DMRS is needed |
| Receiver sensitivity to time/frequency error: Channel tracking based on DMRS not possible. |
| Impact to UE implementation | New PUCCH transmission scheme needed |
| Other comments | The name of these schemes should be clarified: are all of the DMRS-less proposals sequence based? If not, then we should use the generic ‘DMRS-less PUCCH’ description we have been using so far. |
| 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 |  |

## 4.2 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: InterDigital | Use case of the scheme: Enable full utilization of available UL resources for PUCCH, such as UL symbols in special slot. In DL-dominated slot configurations (common scenario) such as DDDSU, the UL symbols in special represent a significant fraction of all available UL symbols. The coverage gain from utilizing these resources can be quite significant. |
| Any Restriction to apply the scheme:  |
| Any prerequisite to apply the scheme:  |
| Performance gain | SNR gain:  |
| PAPR/CM gain:  |
| Spec impact: Need to indicate number of repetitions either dynamically or semi-statically. Possible splitting of resource in case “nominal” PUCCH repetition crosses slot boundary. |
| Impact to receiver | Receiver complexity: Processing/combining of multiple PUCCH repetitions in shorter tie period than for existing scheme. |
| Receiver sensitivity to time/frequency error:  |
| Impact to UE implementation | Transmission of multiple PUCCH repetitions in shorter period than existing scheme  |
| Company: Nokia/NSB  | Use case of the scheme: The use case of repetition type B for PUCCH coverage enhancement is unclear, especially when PUCCH cannot use all UL resources, e.g., PUSCH is also scheduled. In addition, the applicability of this solution also depends on the frame structure, e.g., in frame structures where S slot contains only 2 UL symbols then the scheme may only be beneficial for PUCCH repetition with short format (case 1), whereas the benefit of mixing the PUCCH formats across repetitions is unclear (case 3 in the figure below). |
| Any Restriction to apply the scheme: If this scheme is supported, we may need to restrict it for the case when PUCCH repetitions have the same format, i.e. only case 1 and case 4 in the figure above. In contrast, if the intention is to allow different PUCCH formats on different “actual” PUCCH repetitions, it may introduce significant specification impact and complexity at the receiver. |
| Any prerequisite to apply the scheme:  |
| Performance gain | SNR gain:  |
| PAPR/CM gain:  |
| Spec impact: Indication/determination of number of repetitions and PUCCH formats configuration for different repetitions (if different formats are allowed). |
| Impact to receiver | Receiver complexity: Receiver would need to decode different PUCCH formats for one PUCCH transmission, if any, and multiple PUCCH repetitions per slots. |
| Receiver sensitivity to time/frequency error:  |
| Impact to UE implementation |  |
| Company: WILUS | Use case of the scheme: Efficient resource utilization with more UL symbols in TDD for coverage limited UEs (e.g., cell-edge UEs).  |
| Any Restriction to apply the scheme:  |
| Any prerequisite to apply the scheme:  |
| Performance gain | SNR gain:  |
| PAPR/CM gain:  |
| Spec impact: At first, definition of enhanced PUCCH repetition must be clarified, considering differences between PUCCH and PUSCH (e.g., PUCCH format). Then, we can discuss about spec impact such as repetition indication and segmentation rule. Potential solutions in A.I. 8.8.2.1 such as slot boundary relaxation and larger than 14 symbols also can be considered to this issue. |
| 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 |  |
|  |  |  |

## 4.3 (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: Nokia/NSB | Use case of the scheme: Reducing the number of repetitions dynamically can help reducing the overhead. This however comes at the expense of reliability, and vice versa. From our perspective, this solution may introduce some flexibility for the gNB in terms of indicating the number of PUCCH repetitions. However, it cannot be considered as an independent solution for PUCCH coverage enhancement. |
| Any Restriction to apply the scheme:  |
| Any prerequisite to apply the scheme:  |
| Performance gain | SNR gain:  |
| PAPR/CM gain:  |
| Spec impact: Indication mechanism (depending on whether explicit or implicit method is adopted). |
| Impact to receiver | Receiver complexity:  |
| Receiver sensitivity to time/frequency error:  |
| Impact to UE implementation |  |
| Company:Ericsson | Use case of the scheme: Increased PUCCH format 3 coverage without excessive overhead |
| Any Restriction to apply the scheme: No |
| Any prerequisite to apply the scheme: No |
| Performance gain | SNR gain: 5.0 dB in LLS; 3.5 dB MIL vs. no repetition (since dynamic repetition is not supported) |
| PAPR gain: None (uses Rel-15 waveform) |
| Spec impact: DCI carries repetition indication  |
| Impact to receiver | Receiver complexity: Same as Rel-15 |
| Receiver sensitivity to time/frequency error: Same as Rel-15 |
| Impact to UE implementation | UE must receive new DCI content |
| 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 |  |

## 4.4 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: InterDigital | Use case of the scheme: Same as for PUSCH, i.e. improve accuracy of channel estimation. This is especially useful in case “Type-B like” PUCCH repetition is supported since the time span of the DMRS transmissions is shorter. |
| Any Restriction to apply the scheme: As for PUSCH. However, for PUCCH, it may be more applicable in case of PUCCH repetition. |
| Any prerequisite to apply the scheme:  |
| Performance gain | SNR gain:  |
| PAPR/CM gain:  |
| Spec impact: conditions/signalling to apply bundling need to be specified |
| Impact to receiver | Receiver complexity: DMRS processing within a bundle |
| Receiver sensitivity to time/frequency error:  |
| Impact to UE implementation | Need to maintain same phase and same power across slots |
| Company: Nokia/NSB  | Use case of the scheme: This solution could help improving the quality of channel estimation. However, this should be discussed together or decided after the discussion on cross-slot channel estimation solution for PUSCH. |
| Any Restriction to apply the scheme:  |
| Any prerequisite to apply the scheme:  |
| Performance gain | SNR gain:  |
| PAPR/CM gain:  |
| Spec impact: Similar spec impacts/restrictions as for cross-slot channel estimation solution for PUSCH. |
| 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 |  |

## 4.5 Other schemes

Table 11: Comments on the “Other schemes”

|  |  |  |
| --- | --- | --- |
| 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 PUCCHDecouple 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 |  |
| Company:Ericsson | Scheme: A-CSI on PUCCH | Use case of the scheme: Increased PUCCH format 3 coverage without excessive overhead |
| Any Restriction to apply the scheme: No |
| Any prerequisite to apply the scheme: No |
| Performance gain | SNR gain: 5.0 dB in LLS; 3.5 dB MIL vs. no repetition (since dynamic repetition is not supported) |
| PAPR/CM gain: None (uses Rel-15 waveform) |
| Spec impact: DCI triggers CSI on PUCCH. Timing of A-CSI on PUCCH will need to be specified, as well as if DL DCI, UL DCI, or both are used to trigger. Rel-15 CSI content and coding for PUSCH can be reused. |
| Impact to receiver | Receiver complexity: Same as Rel-15 |
| Receiver sensitivity to time/frequency error: Same as Rel-15 |
| Impact to UE implementation | UE must receive new DCI content and transmit according to trigger timing. |
|  |  |  |  |

# 5 References

1. [R1-2007584](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_103-e/Docs/R1-2007584.zip%22%20%5Ct%20%22_parent), “Potential solutions for PUCCH coverage enhancement,” Huawei, HiSilicon, RAN1 #103 e-Meeting, October 26th – November 13th, 2020
2. R1-2008942, “Discussion on Solutions for PUCCH coverage enhancement,” VIVO, RAN1 #103 e-Meeting, October 26th – November 13th, 2020
3. [R1-2007744](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_103-e/Docs/R1-2007744.zip), “Discussion on potential techniques for PUCCH coverage enhancements,” ZTE, RAN1 #103 e-Meeting, October 26th – November 13th, 2020

1. [R1-2007875](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_103-e/Docs/R1-2007875.zip%22%20%5Ct%20%22_parent), “Discussion on potential techniques for PUCCH coverage enhancement,” CATT, RAN1 #103 e-Meeting, October 26th – November 13th, 2020
2. [R1-2007955](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_103-e/Docs/R1-2007955.zip), “On potential techniques for PUCCH coverage enhancement,” Intel Corporation, RAN1 #103 e-Meeting, October 26th – November 13th, 2020

1. [R1-2007995](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_103-e/Docs/R1-2007995.zip%22%20%5Ct%20%22_parent), “Discussion on PUCCH coverage enhancements,” China Telecom, RAN1 #103 e-Meeting, October 26th – November 13th, 2020
2. [R1-2008027](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_103-e/Docs/R1-2008027.zip), “Discussion on PUCCH coverage enhancement,” CMCC, RAN1 #103 e-Meeting, October 26th – November 13th, 2020
3. [R1-2008079](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_103-e/Docs/R1-2008079.zip), “Discussion on PUCCH coverage enhancement,” NEC, RAN1 #103 e-Meeting, October 26th – November 13th, 2020

1. [R1-2008182](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_103-e/Docs/R1-2008182.zip%22%20%5Ct%20%22_parent), “PUCCH coverage enhancement,” Samsung, RAN1 #103 e-Meeting, October 26th – November 13th, 2020

1. [R1-2008272](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_103-e/Docs/R1-2008272.zip%22%20%5Ct%20%22_parent), “PUCCH coverage enhancement schemes,” OPPO, RAN1 #103 e-Meeting, October 26th – November 13th, 2020
2. [R1-2008371](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_103-e/Docs/R1-2008371.zip), “On PUCCH coverage enhancement techniques,” Sony, RAN1 #103 e-Meeting, October 26th – November 13th, 2020

1. [R1-2008379](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_103-e/Docs/R1-2008379.zip%22%20%5Ct%20%22_parent), “Discussion on PUCCH coverage enhancements,” Panasonic Corporation, RAN1 #103 e-Meeting, October 26th – November 13th, 2020
2. [R1-2008400](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_103-e/Docs/R1-2008400.zip), “PUCCH coverage enhancement,” Sharp, RAN1 #103 e-Meeting, October 26th – November 13th, 2020
3. [R1-2008404](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_103-e/Docs/R1-2008404.zip), “Discussions on PUCCH coverage enhancement,” LG Electronics, RAN1 #103 e-Meeting, October 26th – November 13th, 2020

1. [R1-2008420](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_103-e/Docs/R1-2008420.zip%22%20%5Ct%20%22_parent), “PUCCH coverage enhancement,” Ericsson, RAN1 #103 e-Meeting, October 26th – November 13th, 2020
2. [R1-2008484](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_103-e/Docs/R1-2008484.zip), “PUCCH coverage enhancements,” InterDigital, Inc, RAN1 #103 e-Meeting, October 26th – November 13th, 2020
3. [R1-2008560](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_103-e/Docs/R1-2008560.zip), “Potential techniques for PUCCH coverage enhancements,” NTT DOCOMO, INC, RAN1 #103 e-Meeting, October 26th – November 13th, 2020

1. [R1-2008627](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_103-e/Docs/R1-2008627.zip%22%20%5Ct%20%22_parent), “Potential coverage enhancement techniques for PUCCH,” Qualcomm Incorporated, RAN1 #103 e-Meeting, October 26th – November 13th, 2020

1. [R1-2008704](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_103-e/Docs/R1-2008704.zip%22%20%5Ct%20%22_parent), “Discussion on approaches and solutions for NR PUCCH coverage enhancement,” Nokia, Nokia Shanghai Bell, RAN1 #103 e-Meeting, October 26th – November 13th, 2020

1. [R1-2008730](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_103-e/Docs/R1-2008730.zip%22%20%5Ct%20%22_parent), “Discussion on potential techniques for PUCCH coverage enhancement,” WILUS Inc, RAN1 #103 e-Meeting, October 26th – November 13th, 2020
2. [R1-2008756](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_103-e/Docs/R1-2008756.zip), “PUCCH coverage enhancements,” Indian Institute of Tech (H), RAN1 #103 e-Meeting, October 26th – November 13th, 2020
3. [R1-2008759](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_103-e/Docs/R1-2008759.zip), “Low-PAPR Sequence-Based Approaches for PUCCH Coverage Enhancement,” EURECOM, RAN1 #103 e-Meeting, October 26th – November 13th, 2020
4. R1-2007483, “[102-e-Post-NR-CovEnh-02] Phase 3: initial collection of simulation results for enhancements,” Moderator, RAN1 #103 e-Meeting, October 26th – November 13th, 2020