**3GPP TSG RAN WG1 #102-e R1-** **200xxxx**

**e-Meeting, August 17th – 28th, 2020**

**Agenda item:** 8.8.2.2

**Source:** Qualcomm Incorporated

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

**Document for:** Discussion/Decision

# Introduction

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

# Summary of submitted proposals and email discussion

There were in total 20 contributions submitted to this meeting under 8.8.2.2. The proposed techniques for PUCCH coverage enhancement are categorized and summarized in the following Table.

The list of supporting companies is based on FL’s understanding of companies’ position expressed in their contributions and email discussion. Companies are welcome to add your name in the list to support a scheme or modify the list if the position is changed.

Table 0: Summary of PUCCH coverage enhancement techniques and supporting companies

|  |  |  |  |
| --- | --- | --- | --- |
| **Proposed PUCCH coverage enhancement techniques** | **Supporting companies (from Tdoc submissions)** | **Expressed support or OK to study (during email discussion)** | **Total # proponents** |
| Sequence based DMRS-less PUCCH | ZTE/Sanechips, Huawei/HiSi, NEC, CMCC, QC, Interdigital, Sharp, EURECOM (10) | IITH, CeWiT, IITM, Reliance Jio, Tejas Networks, Apple, OPPO (7) | 17 |
| PUSCH repetition Type-B like PUCCH repetition | VIVO, Huawei/HiSi, Panasonic, WILUS, Samsung (6) | IITH, CeWiT, IITM, Reliance Jio, Tejas Networks, ZTE/Sanechips, CMCC, Intel, E///, Sony, Apple (12) | 18 |
| (Explicit or implicit) Dynamic PUCCH repetition factor indication | OPPO, ZTE/Sanechips, CATT, Ericsson, QC, Samsung (7) | Huawei/HiSi, Panasonic, Intel, E///, Apple (6) | 13 |
| Sequence based PF 0/1 with Pi/2 BPSK | IITH, CeWiT, IITM, Reliance Jio, Tejas Networks (5) | ZTE/Sanechips, OPPO, E///, QC (5) | 10 |
| Pre-DFT data-RS multiplexing for PF2 with Pi/2 BPSK | IITH, CeWiT, IITM, Reliance Jio, Tejas Networks (5) | QC, E/// (2) | 7 |
| DMRS bundling for PUCCH | Intel, CATT, VIVO, NEC, Panasonic (5) | Samsung, ZTE/Sanechips, IITH, CeWiT, IITM, Reliance Jio, Tejas Networks, CMCC, Interdigital, OPPO, E///, Huawei/HiSi, Sony, Wilus, Sharp, Apple (18) | 23 |
| Compact UCI | OPPO, QC, Nokia/NSB (low priority), Sony (5) | ZTE/Sanechips (2) | 7 |
| Freq hopping enhancement for PUCCH | Intel, NEC, Panasonic, Wilus (4) | CMCC, EUROCOM, Apple (3) | 7 |
| Short/mini-slot PUCCH repetition | DCM, Panasonic, Sharp, QC (4) | VIVO, Interdigital, OPPO, E///, Huawei/HiSi (6) | 10 |
| Power control enhancement for PUCCH | Huawei/HiSi, Sony, Samsung, IITH, CeWiT, IITM, Reliance Jio, Tejas Networks (9) | E/// (1) | 10 |
| Increase maximum # allowed repetitions for PUCCH | OPPO, Intel, CATT, Samsung (4) | ZTE/Sanechips, Huawei/HiSi, DCM, Apple (6) | 10 |
| PUCCH Transmit diversity scheme | Intel, CATT, Sony (3) | ZTE/Sanechips, Samsung, E///, Interdigital, OPPO (6) | 9 |
| DMRS overhead reduction | OPPO, Intel (2) | VIVO, Samsung, CMCC, CATT, Apple (5) | 7 |
| UE Antenna configuration enhancement for FR2 | Sony (1) |  | 1 |
| Higher DMRS density | Intel (1) | VIVO, Samsung, ZTE/Sanechips, CMCC, CATT, Nokia/NSB, E///, Huawei/HiSi, Sony, Apple (13) | 14 |
| A-CSI on PUCCH | Ericsson (1) |  | 1 |
| Symbol-level PUCCH repetition | Panasonic (1) | Samsung, ZTE/Sanechips, OPPO (4) | 5 |
| Relay (including sidelink relay) | Sony (1) |  | 1 |
| Reflective arrays | Sony (1) |  | 1 |
| Split UCI payload on short and long PUCCH on adjacent S and U slots | Nokia/NSB |  | 2 |

Note: The last row of the table was added by FL after the first round of email discussion. In the email discussion, Nokia/NSB clarified their proposal should not be categorized into type-B PUCCH repetition. Then this new proposal was added to the table. Since this scheme was not fully discussed in the first round of email discussion. FL suggest to include it in the second proposal to give it a fair chance to be discussed in 2nd round email discussion.

Based on the technique pros and cons, gain observed from initial LLS results, and interest level to study of the proposed scheme, the following proposals are made. The first two schemes can be applied to PUCCH without repetition, given PUCCH repetition has restrictions/drawbacks as discussed in the email discussion. The rest of the schemes in proposal 1 can be applied to PUCCH with repetitions. Combining the merits of the two sets of schemes should be able to boost the PUCCH coverage in most of the NR scenarios and use cases.

Agreements:

Contingent on all of the outcome of sub-agenda 8.8.1 regarding PUCCH enhancements, prioritize the study of the following schemes for PUCCH coverage enhancement,

* DMRS-less PUCCH
  + FFS: design detail for DMRS-less PUCCH, e.g., sequence based PUCCH transmission, v.s. reuse Rel-15 scheme to transmit UCI without DMRS
* Rel-16 PUSCH-repetition-Type-B like PUCCH repetition at least for UCI <=11 bits.
* (Explicit or implicit) Dynamic PUCCH repetition factor indication
* DMRS bundling cross PUCCH repetitions
  + Including study of transmitting a subset of PUCCH repetitions without DMRS, at least for UCI<=11 bits

Note 1: other schemes are not excluded.

Note 2: the study on DMRS bundling for PUCCH repetition can be a joint study with DMRS bundling for PUSCH repetition studied under 8.8.2.1.

Note 3: Companies are invited to report details of the receivers used in the evaluation. Advanced receiver can be included (not mandatory) in performance evaluations. Performance and receiver complexity are discussed respect to a baseline Rel-15/16 PUCCH scheme.

Note 4: proposed PUCCH repetitions scheme shall account for the resources used by PUSCH to meet the throughput target and should be compared against Rel-15/16 PUCCH repetition framework.

[Note 5: enhancement on one or more PUCCH formats/UCI types may or may not be needed, depends on the outcome of sub-agenda 8.8.1]

Agreements:

Deprioritize the study of the following schemes for PUCCH coverage enhancement

* UE Antenna configuration enhancement for FR2
* Relay (including sidelink relay)
* Reflective arrays

***Proposal 2: The following schemes for PUCCH coverage enhancement can be further studied***

* Sequence based PF 0/1 with Pi/2 BPSK
* Pre-DFT data-RS multiplexing for PF2 with Pi/2 BPSK
* UCI size reduction
* Freq hopping enhancement for PUCCH
* Short/mini-slot PUCCH repetition
* Power control enhancement for PUCCH
* Increase maximum # allowed repetitions for PUCCH
* PUCCH Transmit diversity scheme
* Symbol-level PUCCH repetition
* Split UCI payload on short and long PUCCH on adjacent S and U slots
* Potential higher DMRS density for PUCCH with repetitions

Table: comment on Proposal 2

|  |  |
| --- | --- |
| Company name | Comment on Proposal 2 |
| vivo | For ‘Sequence based PF 0/1 with Pi/2 BPSK’ and ‘Pre-DFT data-RS multiplexing for PF2 with Pi/2 BPSK’, we did not observe the performance bottleneck for PUCCH with 1-2bits UCI length, using PF1. Secondly, from coverage perspective, long PUCCH formats is more likely to be used than short PUCCH. Besides, for pi/2 BPSK, according to the MPR reduction defined by RAN4, the power unlocked by introducing pi/2 BPSK compared with QPSK is marginal. Therefore, we would like to deprioritize it, i.e. move it to proposal 3.  For ‘Increase maximum # allowed repetitions for PUCCH’, it also seems not necessary since the PUCCH transmission is postponed due to collision with DL resource or canceled by SFI. The number of PUCCH repetitions seems enough.  For transmission diversity, it is highly related to number of Tx UE antennas and depends on UE capability, it is not a universally effective way for UL coverage enhancements. Furthermore, the transmission diversity can be achieved transparently to gNB for capable UEs. Therefore, we would like to deprioritize it, i.e. also move it to proposal 3.  FL moved comments from VIVO on proposal 3 in FL summary V33 to under proposal 2. In summary, VIVO propose to further deprioritize the following in proposal 2:   * Sequence based PF 0/1 with Pi/2 BPSK * Pre-DFT data-RS multiplexing for PF2 with Pi/2 BPSK * PUCCH Transmit diversity scheme |
| IITH, IITM, CEWIT, Tejas Networks, Reliance Jio | Whether or not coverage bottlenecks are identified depends on the metrics chosen. For now, we can further study all the schemes mentioned in proposal-2.  Request to capture “Pi/2 BPSK-based enhancements such as power level enhancements for TDD and FDD systems” under the proposal-2 for further study. |
| Intel | Similar to the agreement for prioritized solutions, we suggest to add “Contingent on all of the outcome of sub-agenda 8.8.1 regarding PUCCH enhancements,” in the main bullet, as for the same reason we mentioned multiple times during the discussion.  We would like to clarify our understanding of “can be further studied” vs “prioritizing study”. “can be studied” means that companies are encouraged to study with best effort.  For the detailed solution, our understanding is that short PUCCH format would not be considered for PUCCH coverage enhancement, including “Sequence based PF 0/1 with Pi/2 BPSK”, “Pre-DFT data-RS multiplexing for PF2 with Pi/2 BPSK”, “Symbol-level PUCCH repetition”, “Short/mini-slot PUCCH repetition”. Short PUCCH format is mainly targeted for latency reduction, which is not used for cell edge UE. We need to improve the coverage based on long PUCCH format, not short PUCCH format. Further, “Symbol-level PUCCH repetition”, “Short/mini-slot PUCCH repetition” are also under the discussion in Rel-17 URLLC. To avoid duplicated work, suggest to consider to remove this from the list or put FFS.  ***Proposal 2: The following schemes for PUCCH coverage enhancement can be further studied***   * ~~Sequence based PF 0/1 with Pi/2 BPSK~~ * ~~Pre-DFT data-RS multiplexing for PF2 with Pi/2 BPSK~~ * UCI size reduction * Freq hopping enhancement for PUCCH * ~~Short/mini-slot PUCCH repetition~~ * Power control enhancement for PUCCH * Increase maximum # allowed repetitions for PUCCH * PUCCH Transmit diversity scheme * ~~Symbol-level PUCCH repetition~~ * Split UCI payload on short and long PUCCH on adjacent S and U slots * Potential higher DMRS density for PUCCH with repetitions |
| Samsung | Ok to have such agreement with a list of solutions. The wording “can be studied” is fine. The list can be pruned: some topics do not even belong to this SI (UCI size reduction, mini-slot) and some others have been suggested to be removed already in previous rounds of comments – at least such topics should be deleted. |
| QC | We support to further study “Sequence based PF 0/1 with Pi/2 BPSK”. Rel-16 defined new Pi/2 BPSK based CGS that can further reduce the PAPR by 1.3 dB on top of the Rel-15 QPSK CGS. See the following figure from a study carried out under “low PAPR RS” sub-agenda in Rel-16. All that is necessary is for us to reuse those already specified length-12 Pi/2 BPSK sequences on PF0/1. There is very minor spec impact to explore 1.3dB PAPR gain, why not consider it?    We also support to study preDFT multiplex of RS and data. This is a scheme which can generate a DFT waveform with even PUCCH is contained to a single symbol. The immediate use case is to apply it on PF2 to improve the coverage of PF2.  In general, we are open to study coverage enhancement for short PUCCH, i.e., PF0/2. In out understanding, PF 0/2 is used widely by operators (such as DCM) because of its flexibility to fit into small portion of UL time resource. Enhancing short PUCCH coverage can be beneficial. This might be particularly useful in FR2 deployments.  Besides, we support Intel’s suggestion to remove “Short/mini-slot PUCCH repetition” and “Symbol-level PUCCH repetition” from proposal 2, because these schemes are in active discussion under Rel-17 URLLC enhancement. And it is more suitable to discuss these two schemes under URLLC. |

For the schemes agreed in proposal 1, to facilitate alignment of simulation results among different companies, a set of simulation assumptions needs to be agreed. To do this, FL suggest to use the PUCCH simulation assumptions agreed under 8.4.1 in RAN1#101e as a baseline and add additional simulation assumptions on top of it. In the table provided below, companies are welcome to input with your answer to question 1 and provide your view on what additional simulation assumptions are needed to conduct performance evaluation for the schemes agreed in proposal 1.

***Question 1: Is it agreeable to use PUCCH simulation assumptions agreed under 8.4.1 in RAN1#101e as a baseline to conduct link level simulations for the agreed prioritized PUCCH coverage enhancement schemes under 8.8.2.2?***

|  |  |  |
| --- | --- | --- |
| Company name | Answer to question 1 | Proposal of additional simulation parameters, if needed |
| InterDigital | Yes, for now | There could be additional simulation assumptions needed to evaluate enhancement schemes. However, given the limited time, we propose the following:  Proposal : For PUCCH evaluation, if applicable, additional evaluation assumptions are reported by companies. |
| Intel | Defer to next meeting after clear understanding of solutions | We are fine to consider agreed simulation assumptions in the last meeting as a baseline. However, we suggest to defer discussion of simulation assumptions in the next meeting after we have clear understanding on the solutions we need to study. |
| Samsung |  | So far, there are agreed baseline simulation assumptions for FR1 PUCCH in RAN1#101-e and for FR2 PUCCH in RAN1#102-e. We assume these are the baseline assumptions to use and more assumptions (one example is a PUCCH length shorter than 14OS) will be used as needed and reported by companies. |
| QC | Yes | Regarding additional simulation assumptions/parameters for PUCCH simulations, we think companies should report this info in the contributions they submit to RAN1 #103e, together with the simulation results. |

# Discussion

The following subsections capture companies input to the first round of email discussion.

## Sequence based DMRS-less PUCCH

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

Table 1: Comments on the “Sequence based DMRS-less PUCCH”

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Company name | LLS gain observed over Rel-15 baseline | Pros. of the proposed scheme | Cons. of the proposed scheme | Other comments |
| vivo | FFS |  | 1, Unclear performance gain.  2, A new PUCCH format may bring about noneligible spec effort. | As proposed by several companies, the motivation of sequence based PUCCH is to enhance UCI with 3-11 bits. However, the sequence based detection can also be performed based on current PUCCH format 3, the modulated symbols can be considered, as well as the DMRS symbol, can be considered as a long sequence, ML sequence detection can be performed at gNB by implementation. Therefore, the enhanced scheme should be compared with current PUCCH format 3 with the ML sequence detector in LLS. |
| Samsung |  |  |  | Need to first conclude on a set of LLS assumptions, on a set of specific sequences and on 1-2 specific schemes (e.g. “short” or “long” sequences). Comparisons should consider enhancements to Rel-16 PUCCH formats (e.g. improved channel estimation) and also consider bursty interference (e.g. 1-2 lost symbols) and not only AWGN+fading. Some of the solutions grouped under this category might be quite different, details are needed to understand them and potentially evaluate them. |
| ZTE | About 3dB gain for 11 bits UCI | 1. Clear performance improvement without causing more time/frequency resources. 2. More multiplexing capacity. If we use a same sequence pool with up to 2^11 sequences for 3~11 bits. 1~X UEs could be multiplexed in the same time/frequency resources. X could be theoretically up to 2^8 if all UEs are with 3 bits UCI. 3. Lower processing latency at gNB side. Given no channel estimation is needed, gNB can check different hypotheses in parallel. |  |  |
| IITH, CeWiT, IITM, Reliance Jio, Tejas Networks |  |  |  | Support the proposal with sequence-based transmission when the payload < X bits and for > X bits we support pre-DFT-based transmission. |
| CMCC | 3~4dB compared to PUCCH format 3 | The short sequence combination based PUCCH can reduce the required number of sequences in sequence pool. Therefore, The sequence detection complexity is reduced at the receiver. |  | The gain is obviously compared to other solutions.  Details designs can be further studied. |
| InterDigital |  | Allows noncoherent detection of the sequence, ideal for power limited UE experiencing low SNR, improves bandwidth by avoiding the use of DMRS, |  |  |
| CATT | FFS |  | 1. Huge specification impacts 2. High complexity for gNB detection | It may be true we can obtain gains from sequence-based PUCCH format. But we should also carefully evaluate the effort on standardization. From our perspective, we should go with the more moderate solution with less specification impacts to compensate the performance gap. |
| Nokia/NSB |  | DMRS-less noncoherent transmission may offer better performance at low SNR, as compared to its DMRS-based coherent counterpart, due to poor channel estimation or low coding gain of the latter at low SNR | 1. Potential for performance gain and conditions to achieve it are not clear, especially in the context of a comparison with other proposed techniques. 2. A new PUCCH format may entail non-negligible specification effort.   Extending the sequence-based noncoherent transmission technique to transmit more than 2 bits UCI would require a rather large sequence pool and consequently entail larger complexity burden to the receiver. | * Since time allocated for this SI is limited, discussion on receiver complexity and optimized implementations should be avoided for the sake of efficiency. * Agree with Samsung on how performance should be assessed and compared with other enhancements. |
| Panasonic |  |  |  | The main use case would be for low/medium payload size. |
| OPPO | FFS | Better performance in low SNR due to the non-coherent demodulation and the 0 overhead of DMRS | More spec impact of introducing the new PUCCH format. The potential new configuration will depends on how the PUCCH is designed | Regarding the detailed schemes of dmrs-less PUCCH, the further details should be converged to seem if all the companies are proposing same thing.  We can consider it for better comparison. We are open for the scheme. In addition: We think No. 1, 2, 4, 5, 9, 12, 13 (corresponding to the tables index)could be categorized as PUCCH format enhancement. (enhanced repetition can also introduce new configuration similar as a new format)  We can compare them. |
| EURECOM | Short payload (4bits): 1-2dB coding gain and 1-2dB shaping gain  Longer payload (11 bits): 3-4dB coding and 1-2dB shaping | In agreement with pros provided by ZTE.  Additionally:  1. for longer payloads (11 bits), through structured coding techniques combined with low PAPR sequences, there is potential for lower complexity receivers.  2. potential for designing sequences/codes for unequal error protection (lower error probabilities for ACK/NACK than CSI) |  | High priority.  Coding gains expressed wrt optimal non-coherent detection of Rel-15 waveform.  Shaping gain here corresponds to minimizing PAPR |
| Intel |  |  | Substantial spec impact regarding sequence design to accommodate different number of symbols allocated for PUCCH, the number of PRBs, and UCI payload size.  High gNB detection complexity. | We share similar view as Samsung/Nokia and Vivo. Need to first agree on the simulation assumptions to compare the performance. Existing PUCCH format 3 with ML detection (without DMRS) may offer comparable performance compared to sequence based PUCCH. |
| Ericsson |  |  | Performance gain is not clear to us especially with respect to advanced receivers, complexity compared to the gain might be high | Data-aided channel estimation should be considered as a baseline in the evaluation |
| Huawei, Hisilicon | gain over PUCCH format 3 with UCI 4~11 bits is related to detection complexity, which increases as payload size increase. | Versatile for any PUCCH resource allocation;  Good sequence cross-correlation properties;  Very low PAPR (<3dB) |  |  |
| Qualcomm | 3-4 dB | This scheme is particularly well-suited for cell-edge UEs that operate in the low SNR regime. Additionally, this scheme does not rely on any repetitions or cross-slot enhancements to improve PUCCH performance. This scheme can be considered a direct extension of PF0, thus there already exists a good precedence to pursue such techniques.  Additionally, the sequence-based design has the following salient features:  **Efficient resource utilization:**  This schemes wastes zero resources towards DMRS. All available power and time-freq resources are used towards transmitting the payload. No resources/no power is wasted in DMRS.  **gNB receiver complexity reduction:**  Contrary to the common assumption, this scheme actually reduces gNB complexity for PUCCH recovery for small payload sizes (e.g. 11 bits). Lack of channel estimation overhead leads to significant cost savings. When efficient techniques are used, sequence detection does not significantly add to the overall complexity. On the whole, we see an overall simplification of the gNB receiver design.  It is worth mentioning that not all ML receivers incur a large complexity and it would be incorrect for us to blindly reject them. We in fact already use an ML receiver for PF0, thus illustrating the value of ML receivers under specific scenarios. ML receivers for reasonable payload sizes are well within the complexity budget of current gNB architectures.  **Performance gains:**  There are significant performance gains from this scheme. We and a few other companies have observed a clear 3-4 dB gain when compared to R15 baselines and typical gNB receiver design.  **Simple implementation on UE side:**  This scheme is quite lightweight and easy to implement on the UE side. No additional restrictions (for e.g., phase coherence) are necessary on the UE transmissions. |  | Every enhancement being considered comes with a certain impact on the spec. Spec impact should not determine the enhancement we pursue --- extending this logic would lead us to not pursuing any enhancement as it has no spec impact. This is not desirable and we do not wish to be evaluating enhancements through these lens.  @VIVO, in our Tdoc R1-2006821, Fig 4 compares the new scheme vs Rel-15 baseline scheme with 2 bits UCI. ML receiver (including DMRS of baseline scheme in detection) is used for both schemes and the new scheme showed 3 dB gain under ML receiver. |
| SONY |  |  | Ability to transmit a large number of bits would require a large number of sequences which would impact gNB complexity and specification impact. | Agree with vivo that sequence-based PUCCH should be compared with ML sequence detection of modulated symbols sequences / DMRS of existing PUCCH formats. |
| Sharp | FFS | Detection performance degradation by channel estimation error can be avoided. | For the larger number of UCI bits, detection complexity becomes larger. |  |
| Apple |  |  |  | For this scheme, it needs to consider the performance gain (with different payload size), implementation complexity and standard impacts together. We are open to evaluate the scheme further. |

## 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 2: Comments on the “PUSCH repetition Type-B like PUCCH repetition”

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Company name | LLS gain observed over Rel-15 baseline | Pros. of the proposed scheme | Cons. of the proposed scheme | Other comments |
| vivo | Depending on the additional resources can be utilized. | The UL resources in S slot can be utilized together with the resources in U slots. |  |  |
| Samsung |  | Similar pros as for PUSCH. Reduced latency as more available symbols can be used. Enhanced resource allocation. Additional flexibility for gNB scheduling. |  | High priority |
| ZTE |  |  |  | Open to discuss |
| IITH, CeWiT, IITM, Reliance Jio, Tejas Networks |  |  |  | Support the proposal |
| CMCC |  | UL symbols in S slot can be utilized, the PUCCH latency can be reduced |  | It can be studied. Since it is also discussed in NR IIoT/URLLC Enhancements WI, for UE feedback enhancements for HARQ-ACK, coordination is needed |
| InterDigital |  | Allowing repetition across slots will be beneficial for improving SNR and flexibility in placement of PUCCH |  |  |
| CATT |  |  | Don’t see the necessity to introduce type B like PUCCH. The main motivation of PUCCH repetition type B is low latency. It is not relevant to coverage enhancement at all. The current repetition mechanism is sufficient enough. |  |
| Nokia/NSB |  | Exploiting better the available UL resource for PUCCH repetition and hence improving the coverage. | It is hard to assess the actual benefit of such solution in a complete system, given that in TDD deployment if all UL resources are used for PUCCH this also means that there is no resource for PUSCH transmission. In other words, expected coverage performances of PUSCH and PUCCH may not be observed in practice at the same time or the actual data rate of PUSCH is reduced when PUCCH transmission takes place. | In our contribution, the idea is not exactly considering “PUSCH repetition type B like” approach. The idea is some how to split the UCI payload such that part of UCI will be transmitted with short format in S slot and the remaining UCI will be transmitted with long format in full U slot. |
| Panasonic |  | It has the potential to efficient usage of available UL resource. | Since NR defines PUCCH formats depending on the duration of PUCCH, potential impact would be PUCCH format may be different among the actual repetitions. |  |
| OPPO |  | Could use more symbols, especially in certain TDD configuration | Not a universal solution for both TDD and FDD.  It is not optimized for coverage enhancement. |  |
| Intel |  | Latency reduction  PUSCH repetition type B based back to back repetition is mainly targeted for low latency like URLLC. | Typically, back to back repetition is mainly for PUCCH with short duration. However, for coverage enhancement, it is expected long PUCCH format is employed. | Open to discuss it |
| Ericsson |  |  |  | Open to discuss |
| Huawei, Hisilicon |  | More flexible resource utilization to improve uplink coverage if PUSCH repetition Type-B like PUCCH repetition is supported |  |  |
| Qualcomm |  |  | While this may help reduce latency, this doesn’t directly help coverage. Current spec also allows deferring a PUCCH repetition until it finds a legitimate UL slot and this is sufficient for cell-edge UEs.  More generally, we are of the opinion that PUCCH repetitions are unlikely to help a cell-edge UE for the following reasons:   1. it does not help coverage for HARQ-ACK payloads. As number of repetitions grow, each PUCCH now needs to carry more ACK-NACK bits, thus countering whatever benefits repetitions might offer. 2. TDD systems are constrained for uplink resources. We don’t have the luxury of increasing PUCCH repetitions. 3. PUSCH is dropped when it overlaps with a PUCCH repetition in time domain. PUCCH repetition would reduce PUSCH coverage.   Due to these reasons, it is important for us to study a scheme that does not require repetitions to boost PUCCH performance, which should act as a baseline for other potential enhancement. | Do not support this proposal. |
| SONY |  | More resources can be used for PUCCH transmission. |  | Should be studied |
| WILUS |  | Resource efficiency with more available flexible or UL symbols. Low latency in PUCCH transmission and flexible scheduling at gNB. |  | High priority |
| Sharp |  | UL parts in special slots can be utilized. Channel segmentation by TDD pattern is one of the key factor for this SI. |  |  |
| Apple |  |  |  | Is the solution only for TDD and short PUCCH format? We are open to discuss the scheme further |

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

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Company name | | LLS gain observed over Rel-15 baseline | | Pros. of the proposed scheme | | Cons. of the proposed scheme | | Other comments | |
| vivo | | None | |  | | For the explicit scheme, additional bit field would be introduced in DCI, which may degrade the performance of PDCCH.  For the implicit scheme, does it mean dynamically determine the number of PUCCH repetitions? In our opinion, in current spec, UE can select different PUCCH resource set according to UCI bits, and different repetition numbers can be configured to different PUCCH resource set. Therefore, current PUCCH resource set selection rule is quite flexible to support determine the number PUCCH repetition number implicitly. | |  | |
| Samsung | |  | | Can adapt to UCI payload and total number of available REs/symbols for repetitions. An RRC-only indication needs to account for a “worst case” scenario and is too wasteful. | |  | | Details of the signaling can be left for later discussions, after 2.2 progresses. | |
| ZTE | |  | | 1. Resource efficient. To ensure the reliability of PUCCH, gNB has to semi-statically a conservative repetition factor in Rel-15. A more appropriate repetition factor can be indicated by dynamic repetition which would be more resource efficient. 2. Enable more flexibility for gNB to avoid collision of PUSCH. In Rel-15, when PUCCH repetition overlaps with PUSCH, PUSCH would be dropped. This would impacts system efficiency a lot. | |  | |  | |
| CATT | |  | |  | | |  | | Open to discuss as alleviate the overhead issue if more repetition is introduced. | |
| Nokia/NSB | |  | | Dynamic indication of repetition number could help providing more flexibility for the gNB to adjust the number of PUCCH repetitions. | | | Explicit indication (e.g. by DCI) may increase the DCI payload.  The benefit of this approach in terms of LB is unclear since, once the number of repetitions is known by the UE, the exact number of repetitions will be performed regardless of dynamic indication or static configuration of number of repetitions. | |  | |
| Panasonic | |  | | Resource efficiency can be improved. The coverage of PUCCH transmission may be changed dynamically based on the payload size and channel condition. Therefore, it would be beneficial to introduce dynamic indication of the number of PUCCH repetitions. | | |  | | The number of repetitions can be indicated as an additional parameter in the PUCCH resource set. This does not increase the DCI overhead. | |
| OPPO | |  | | Dynamic indication is important for the case with higher aggregation factors of PUCCH. UE configured with a large factors will be wasteful for transmit multiple times without adapatation. | | |  | |  | |
| Intel | |  | | More flexibility on scheduling. | | | Typically, dynamic indication of PUCCH is applied in conjunction with repetition type B. For coverage enhancement, it is not clear the benefit for dynamic indication. | | Open to discuss it. | |
| Ericsson | |  | | More flexibly configured repetition factors based on the link adaptation can be dynamically signalled. And this is more important for A-CSI on PUCCH which can be introduced to improve the A-CSI performance. | | |  | | We’re open to discuss the details of the indication later, e.g. in a implicit or explicit manner. We should try to avoid increasing the bits in DCI for the indication if possible. | |
| Huawei, Hisilicon | |  | | By dynamic PUCCH repetition factor indication, better match of fading channels with suitable repetition number can improve the uplink transmission ability | | |  | |  | |
| Qualcomm | |  | | There are two aspects to coverage enhancement --- one concerns improving the link budget of various PHY channels under steady-state operation and the second involves improving overall link reliability leading to lower probability of link failure.  Sensitive UE/gNB operations such as beam switching can result in link failure if not properly managed. We would like to minimize the overall instances of such events leading to link failure. In this context, we think having additional flexibility in determining PUCCH repetition is valuable. For example, there can be scenarios in FR2 where UE acknowledges the reception of a PDSCH that carried beam switching information and it might be beneficial to consider additional robustness for this message. | | |  | |  | |
| SONY | |  | | Dynamic change of PUCCH repetitions would allow the system to react to changing UCI payload or channel conditions without RRC signalling. | | | Explicit fields in DCI would increase DCI payload and impact DCI performance. | |  | |
| Apple | |  | | Indication of the repetition number flexibly and adaption to the link quickly. | | |  | | Open to discuss | |

## Sequence based PF 0/1 with Pi/2 BPSK

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

Table 4: Comments on the “Sequence based PF 0/1 with Pi/2 BPSK”

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Company name | LLS gain observed over Rel-15 baseline | Pros. of the proposed scheme | Cons. of the proposed scheme | | Other comments | |
| vivo | FFS |  |  | | Based on RAN4 MPR requirement, the MPR for PUCCH format 0/1 is 0 for inner RB allocation. Therefore, low PAPR transmission can be realized by proper gNB configuration. Therefore, the additional gain brought by pi/2 BPSK for PF0/1 is doubtful. | |
| Samsung |  | Can improve coverage | | Requires changes to UE implementations. | | Neutral |
| ZTE |  |  | |  | | Fine to discuss but we don’t see much motivation on enhancement of PF0/1 |
| IITH, CeWiT, IITM, Reliance Jio, Tejas Networks |  | Improves Coverage. Can align the transmission characteristics when PUSCH and its DMRS use pi/2 BPSK. |  | | High priority. | |
| CATT |  |  | Don’t see the necessity to enhance PF#0 and PF#1, especially PF#0 with short duration. | | Low priority. | |
| OPPO | FFS | Low PAPR will help the coverage. |  | |  | |
| Intel |  | PAPR reduction | Multiplexing capacity may be reduced due to non-orthogonality between the sequences using pi/2 BPSK in Rel-16. | |  | |
| Ericsson |  |  |  | | Fine to study to investigate the gain. | |
| Huawei, Hisilicon |  |  |  | | Don’t see PF 0/1 is a bottleneck. Low priority | |
| Qualcomm |  |  |  | | Switching to pi/2 BPSK waveform reduces PAPR and this is beneficial for uplink transmissions. We support this proposal. | |
| Apple |  |  |  | | Less motivation to further enhance the FP 0/1. | |

## Pre-DFT data-RS multiplexing for PF2 with Pi/2 BPSK

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

Table 5: Comments on the “Pre-DFT data-RS multiplexing for PF2 with Pi/2 BPSK”

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Company name | LLS gain observed over Rel-15 baseline | Pros. of the proposed scheme | Cons. of the proposed scheme | | Other comments | |
| vivo |  |  |  | | We prefer PUCCH based on long PUCCH format, and enhancements based on PF2 should be deprioritized. | |
| Samsung |  |  | |  | | Deprioritize |
| ZTE |  |  | |  | | Same as about. We don’t see much motivation on enhancement of PF2 |
| IITH, CeWiT, IITM, Reliance Jio, Tejas Networks |  | Significantly improves coverage. There is a significant disconnect between transmit power characteristics of low PAPR waveforms being considered and the PUCCH formats of CP-OFDM. This gap must be bridged. Pre-DFT can send arbitrary payloads just like CP-OFDM. |  | | High priority | |
| CATT |  |  |  | | Low priority | |
| Panasonic |  |  |  | | Enhancements of short PUCCH format can be deprioritized. | |
| OPPO |  | Similar as last one. | Reduced UCI payload would be more preferable. | |  | |
| Intel |  | Reduce PAPR | In our view, coverage enhancement should target for long PUCCH format with longer duration. | |  | |
| Ericsson |  |  |  | | Fine to study. | |
| Huawei, HiSilicon |  |  |  | | As commented before, low priority. | |
| Qualcomm |  |  |  | | For PF2, Pre-DFT RS-data multiplexing enables DFT-S-OFDM waveform which has lower PAPR compared to CP-OFDM. Additionally, allowing pi/2 BPSK waveform further reduces PAPR and this is beneficial for uplink transmissions. We support this proposal. | |
| Apple |  |  |  | | Low priority for enhance PF2 | |

## DMRS bundling for PUCCH

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

Table 6: Comments on the “DMRS bundling for PUCCH”

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Company name | LLS gain observed over Rel-15 baseline | Pros. of the proposed scheme | Cons. of the proposed scheme | Other comments |
| vivo | Around 1dB | Channel estimation accuracy can be improved. And this scheme is easy to be implemented. |  |  |
| Samsung |  | Improved channel estimation | Possible restrictions and not readily available | OK to study |
| ZTE |  |  |  | OK to study |
| IITH, CeWiT, IITM, Reliance Jio, Tejas Networks |  |  |  | Support the proposal |
| CMCC |  | This is helpful to improve channel estimation. |  | It can be studied. |
| InterDigital |  | DMRS sharing for PUCCH repetition improves channel estimation performance and overhead reduction |  |  |
| CATT |  |  |  | Open to study. |
| Nokia/NSB |  |  | The feasibility of DMRS bundling should be further discussed either in PUSCH enhancement AI or this AI, since this technique is only beneficial under certain constraints, e.g., consecutive transmissions should experience the same physical channel properties, devices should move at low speed etc. This drawback may be even harder to tackle in TDD deployment, since the number of contiguous UL slots per frame is rather small or could even be zero. |  |
| Panasonic |  | In poor channel conditions, the improvement of channel estimation performance is essential. |  | It should be studied. |
| OPPO |  | Could be used in the receiver implementation |  | Not a format design. As we mentioned in table 1. Can be discuss as another enhancement dimension. |
| Intel | >1dB gain as observed in R1-2005890 | This is evident that substantial link level performance gain can be achieved if cross-slot channel estimation is employed. It is extremely important due to the fact that channel estimation performance is typically a bottleneck at low SNR regime. Using DMRS bundling can improve the channel estimation performance and thus overall decoding performance. | UE needs to maintain phase continuity within DMRS bundling size. | Open to discuss it. Same solution can be applied for PUSCH coverage enhancement |
| Ericsson |  |  |  | Fine to study. |
| Huawei, Hisilicon |  | A better channel estimation by DMRS bundling can improve PUCCH transmission performance | FFS |  |
| Qualcomm |  |  | This assumes PUCCH repetitions. PUCCH repetitions are not universally useful. In particular, repetitions are not practical when considering HARQ-ACK payload. | Low priority |
| SONY |  | Improved channel estimation. |  | OK to study |
| WILUS |  | Channel estimation performance improvement and less specification impact. |  | High priority |
| Sharp |  | Several companies including us indicates benefit from DMRS bundling by LLS. |  |  |
| Apple |  |  |  | Open to discuss. The similar solution can be applied to both PUSCH and PUCCH. |

## Compact UCI

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

Table 7: Comments on the “Compact UCI”

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Company name | LLS gain observed over Rel-15 baseline | Pros. of the proposed scheme | Cons. of the proposed scheme | Other comments |
| vivo | FFS | Lower coding rate can provide better coverage | DL coverage may be degraded due to some UCI information, e.g. CSI, is dropped. While DL coverage is far better than UL coverage, the DL performance loss is acceptable. |  |
| Samsung |  |  |  | Deprioritize |
| ZTE |  |  |  | Not sure how to compact the UCI. Maybe proponents can clarify more and we are fine to further study if it doesn’t impact the system efficiency too much. |
| CMCC |  |  | Downlink peformance may be reduced | Deprioritize |
| CATT |  |  | It has big impacts on specification but has doubtful benefits. | Low priority |
| Nokia/NSB |  | Reduce the coding rate. | May reduce downlink performance. | This item may be deprioritized. Assessing the gain brought by this approach may not be trivial and should be further evaluated. |
| OPPO |  | We should focus on small payload of UCI, since the coverage limited case does not requirement very dedicated CSI. |  | We should focus one low payload size for all PUCCH enhancement. |
| Intel |  | Coding rate reduction | May reduce DL performance | Low priority |
| Ericsson |  |  |  | We would like to better understand the downlink performance degradation vs. uplink coverage gains tradeoffs. |
| Qualcomm |  | This enhancement is worth considering especially in the FR2 context, where L1 beam report can potentially be compressed further. |  | We support this proposal. |
| SONY |  | Reduction in coding rate through transmission of less CSI or through HARQ A/N bundling | May reduce downlink performance, depending on accuracy of CSI at cell edge. |  |
| Sharp |  | PUCCH format 1 can be reused by time domain HARQ-ACK bundling. |  |  |
| Apple |  |  |  | The pros and cons are not clear enough. Propose to have low priority. |

## Freq hopping enhancement for PUCCH

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

Table 8: Comments on the “Freq hopping enhancement for PUCCH”

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Company name | LLS gain observed over Rel-15 baseline | Pros. of the proposed scheme | Cons. of the proposed scheme | Other comments |
| vivo | Around 1dB | Easy to be implemented, and spec impact is limited. |  |  |
| Samsung |  |  | No benefit as with 4 gNB Rx antennas and 1 FH, all diversity benefits are obtained. | Deprioritize |
| IITH, CeWiT, IITM, Reliance Jio, Tejas Networks |  |  |  | No support |
| CMCC |  |  |  | It can be studied to see the gain. |
| Panasonic |  | Configurable time domain hopping interval can obtain both frequency diversity gain and channel estimation improvement. |  | Configurable time domain hopping interval should be studied in the combination with cross-slot/cross-repetition channel estimation. |
| EURECOM |  | May be worth considering to tackle scenarios where frequency dependent interference is dominant (potentially more than 2 frequencies) | Agree with Samsumg wrt frequency diversity against fading | Ok to study |
| Intel | ~1.5dB gain as observed in R1-2005890 | The following schemes can be considered:  1. with more frequency hops to further exploit the benefit the frequency diversity.  2. PUCCH transmission stays in N slot in a frequency resource before it switches to another frequency resource.  3. For the case when π/2-BPSK is used, cyclic shift of PUCCH sequences is not supported and sequence group hopping can be enhanced where f\_gh is a function of the OFDM symbol index within the radio frame. This helps improve PUCCH coverage in part by improving the inter-cell interference randomization for PUCCH DM-RS sequences. | For more than 2 frequency hops, the performance depends on UL BWP BW. When the UL BWP BW is small, performance gain with more than 2 hops is limited.  Possibility of sequence collision is still non-zero, but it significantly reduces the overall cross-correlation for multiple DM-RS within a slot. | Same solution for PUSCH. High priority |
| Ericsson |  |  | We do not expect obvious gain via optimizing FH and do not see the need to further enhance FH of PUCCH given up to 8 repetitions can already been supported for long PUCCH. |  |
| Huawei, Hisilicon |  | More flexible frequency hopping can fully utilize the diversity in frequency domain to improve uplink transmission. | PUCCH usually allocated at edges of schedule PRBs, flexible frequency hopping positions would cause dis-continuous resource allocation for data channel and distort the low PAPR | Low priority |
| Qualcomm |  |  | Additional hops lead to significant increase in DMRS overhead. This is not desirable. The gain is highly dependent on channel statistics and current evaluation assumptions do not accurately model channel statistics for MMIMO systems. | Low priority |
| SONY |  | Time domain hopping interval can improve channel estimation. More hops could improve frequency diversity. | There may be limited benefit to more hops if diversity is obtained by other means (e.g. gNB antennas) or the channel already provides sufficient frequency diversity. |  |
| WILUS |  | Frequency diversity gain and less specification impact. | Frequency hopping enhancement that simply enhanced to obtain hopping gain is not preferable in CE SI. Frequency hopping enhancement should be followed by clear coverage gain. | High priority |
| Apple |  | Frequency hopping enhancement combining with repetition and cross-slot channel estimation could provide the better performance. |  | Similar solution can be applied to both PUSCH and PUCCH, the standard effort is small.  Propose to have high priority. |

## Short/mini-slot PUCCH repetition

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

Table 9: Comments on the “Short/mini-slot PUCCH repetition”

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Company name | LLS gain observed over Rel-15 baseline | Pros. of the proposed scheme | Cons. of the proposed scheme | Other comments |
| vivo |  |  |  | We think this topic can be covered by type-B PUCCH repetition in section 3.2 |
| Samsung |  |  | No need for coverage enhancements. It is currently considered in URLLC. | Deprioritize |
| ZTE |  |  |  | No clear motivation to enhance short PUCCH format. |
| CMCC |  |  |  | Short PUCCH format is not intended for cell edge users. |
| InterDigital |  | Offers flexibility in placement of PUCCH for repetition. This proposal may be considered jointly with 3.2. |  |  |
| CATT |  |  | No. Long PUCCH can be employed. |  |
| Panasonic |  |  |  | Enhancements of short PUCCH format can be deprioritized. |
| OPPO |  |  |  | It can be merged with Type-B like PUCCH |
| Intel |  |  | For coverage enhancement, it is not clear whether short PUCCH repetition needs to be considered. For instance, for 2-symbol short PUCCH, 7 repetitions are needed to reach same coverage target as 14-symbol long PUCCH. | Low priority |
| Ericsson |  |  |  | Fine to study. |
| Huawei, Hisilicon |  |  |  | Better to focus on the bottleneck scheme, but open for discussion. |
| NTT DOCOMO |  |  |  | Short PUCCH format is used for FR2 operation, and it may be a bottle neck channel. Installing repetition for PUCCH short format may be one of the solutions. |
| Sharp |  | Mini-slot repetition can utilize resource in special slots |  |  |
| Apple |  |  |  | Less motivation to enhance the short PUCCH |

## Power control enhancement for PUCCH

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

Table 10: Comments on the “Power control enhancement for PUCCH”

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Company name | LLS gain observed over Rel-15 baseline | Pros. of the proposed scheme | Cons. of the proposed scheme | Other comments |
| vivo |  |  |  | The solution seems not clear? |
| Samsung |  | BLER targets are individually controlled per UCI type in LTE and when multiplexed in PUSCH. But not possible for PUCCH and Tx power needs to always be based on the “worst case” (lowest target BLER). |  | Prioritize - important to provide same capability for individual UCI type target BLER on PUCCH as for PUSCH. |
| IITH, CeWiT, IITM, Reliance Jio, Tejas Networks |  | Power boosting capability of a waveform must be reflected in the power control calculations. Easily provides coverage gains. |  | High priority. |
| CATT |  |  | The current PC is sufficient considering the maximum power always needs to be followed. |  |
| OPPO |  |  |  | Hold until clear scope. |
| Ericsson |  |  |  | Fine to study to determine performance gain. |
| Huawei, Hisilicon |  | We provide FDD higher power UE for PUCCH transmission to enable a better channel estimation where a higher SNR can be obtained. |  |  |
| Qualcomm |  |  |  | Low priority |
| Sharp |  |  | In coverage edge, power control may not work. |  |
| Apple |  |  |  | Not fully clear the solution. |

## Increase maximum # allowed repetitions for PUCCH

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

Table 11: Comments on the “Increase maximum # allowed repetitions for PUCCH”

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Company name | LLS gain observed over Rel-15 baseline | Pros. of the proposed scheme | Cons. of the proposed scheme | Other comments |
| vivo |  |  |  | In current PUCCH repetition mechanism, the PUCCH repetition is postponed if collision with DL or cancelled by SFI, therefore maximum 8 repetitions seems enough. |
| Samsung |  | Straightforward extension of existing solution with minimal specification impact. Provides additional flexibility to gNB to guarantee coverage. Also useful in extreme coverage cases. | Additional latency. | Prioritize. Also determine maximum UCI payload to support for repetitions. |
| ZTE |  |  |  | OK to study |
| InterDigital |  |  | Priority between PUCCH and PUSCH should be considered as increasing the number of PUCCH repetitions may have negative impact on throughput for PUSCH. |  |
| CATT |  |  |  | OK to study |
| Nokia/NSB |  |  |  | Similar comments made for 3.2 |
| Panasonic |  |  |  | Agree with vivo. |
| OPPO |  | Simple solutions and could be sufficient. | Resource efficiency and flexibility should be addressed. |  |
| Intel | ~2dB when doubling the PUCCH repetition level | It is obvious that when increasing repetition level, link budget is improved. | This may depend on the exact target that PUCCH needs to be enhanced. | Open to discuss |
| Ericsson |  |  |  | Unclear why 8 is enough. |
| Huawei, Hisilicon |  | Might be a potential solution for PUCCH coverage enhancement, | but the repetition number of PUCCH will have impacts on PUSCH given limited UL resources. |  |
| Qualcomm |  |  | As stated earlier, repetitions for PUCCH do not help a cell-edge UE when the PUCCH payload includes HARQ-ACK feedback. Also, in TDD systems, uplink resources are limited and we may not have the luxury to keep increasing the number of repetitions. | We don’t support this proposal. |
| NTT DOCOMO |  |  |  | In our understanding, in the current spec, 2/4/8 consecutive slots can be configured for PUCCH repletion, and D/S slots can be dropped, but # of repetition is counted at the D/S slots. Thus although 8 slots are configured, PUCCH can be transmitted at 2 UL slots for DDDSU configuration. |
| Sharp |  | Simple and beneficial. |  |  |
| Apple |  | Simple solution and less standard impacts |  | Support to discuss |

## PUCCH Transmit diversity scheme

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

Table 12: Comments on the “PUCCH Transmit diversity scheme”

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Company name | LLS gain observed over Rel-15 baseline | Pros. of the proposed scheme | Cons. of the proposed scheme | Other comments |
| vivo |  |  | For SORTD, as that introduced in LTE, double resources would be used for two antenna ports.  For frequency domain precoding cycling, it may lead to higher PAPR for PUCCH with DFT-S-OFDM waveform, i.e. PF3 and PF4. | The transmission diversity scheme relies on UE Tx antenna design, the coverage enhancement solutions is preferred not to rely on antenna configuration. |
| Samsung |  | Can be beneficial if no FH to improve channel estimation while achieving all diversity gains. |  |  |
| ZTE |  |  |  | Ok to study |
| IITH, CeWiT, IITM, Reliance Jio, Tejas Networks |  | At low SNR it is important to focus on improving channel estimations using single layer transmissions than training the channels using multiple DMRS. |  | No support. |
| InterDigital |  | Transmission diversity schemes will provide gain in coverage. Tradeoff between complexity and performance can be studied. |  |  |
| CATT | At least 1 dB | A general way to enhance coverage for all the formats. Have significant enhancement with few or no specification impacts |  | OK to study |
| Nokia/NSB |  |  |  | Deprioritize for the reason given by other companies. Ok to study if such is the view of the majority. |
| OPPO |  | The transmit diversity gain can be explored |  |  |
| Intel |  | When UE is equipped with multiple antennas, Tx diversity can help improve the performance by exploiting spatial diversity. Potential solution may include SORTD, etc. |  | Open to discuss it. |
| Ericsson |  |  |  | Ok to study but transparent schemes should be taken into account. |
| Huawei, Hisilicon |  |  |  | In UL transmission, usually UE only has 1-4 antenna with single layer transmission, how much gain can transmit diversity obtain should be clarified |
| Apple |  |  |  | The scope seems too broad, the schemes to be investigated need to be clear. |

## DMRS overhead reduction

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

Table 13: Comments on the “DMRS overhead reduction”

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Company name | LLS gain observed over Rel-15 baseline | Pros. of the proposed scheme | Cons. of the proposed scheme | Other comments |
| vivo | FFS |  |  | When DMRS bundling is introduced, DMRS less PUCCH can also considered. |
| Samsung |  | Unclear | Potential increase in receiver complexity | DMRS overhead reduction solutions, including “DMRS-less” solutions, should be discussed together and compared. |
| ZTE |  |  |  | Not sure what’s the difference/relationship between DMRS bundling and DMRS overhead reduction here. |
| CMCC |  |  |  | This solution is proposed for PUSCH enhancement, it can be studied to see the gain. |
| InterDigital |  | For low mobility scenario, DMRS sharing can reduce DMRS overhead. PUCCH may not have any DMRS and DMRS placed outside of PUCCH can be used for channel estimation. |  |  |
| CATT |  |  |  | Open to discuss. |
| Nokia/NSB |  |  |  | Same view as ZTE. |
| OPPO |  |  |  | Could be considered with DMRS-less schemes. |
| Intel |  | DMRS-less operation in certain slots during PUCCH repetition can be considered. In this case, unused DMRS symbols can be allocated for UCI transmission, which can help reduce UCI code rate and improve PUCCH link budget |  | Share similar view as ZTE/Nokia |
| Ericsson |  |  |  | Gains is not immediately clear. How does reducing overhead of DMRS increase coverage? |
| Huawei, Hisilicon |  | DMRS is important for channel estimation. Pilot overhead reduction might be possible if cross-slot channel estimation and static channel fading is assumed. |  |  |
| SONY |  |  |  | There are several variants on DMRS enhancement identified in this FLS. Maybe they could all be studied under the same framework (e.g. determination of optimum number of DMRS) |
| Apple |  |  |  | Open to discuss |

## UE Antenna configuration enhancement for FR2

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

Table 14: Comments on the “UE Antenna configuration enhancement for FR2”

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Company name | LLS gain observed over Rel-15 baseline | Pros. of the proposed scheme | Cons. of the proposed scheme | Other comments |
| Samsung |  |  |  | Deprioritize, might be discussed in MIMO WI. |
| Nokia/NSB |  |  |  | Deprioritize. Agree with Samsung. |
| OPPO |  |  |  | Deprioritize |
| Ericsson |  |  |  | Seem to be detailed MIMO aspects and may not be within the scope of this study item |
| Qualcomm |  |  |  | Low priority |
| SONY |  | UE antenna spherical coverage and beam correspondence (BC) are key limiting factors for cell coverage that influence outage.  The requirement on UE spherical coverage agreed in RAN4 is compromised, we therefore think that realistic UE antenna/panel implementation may influence the performance of physical channels and, hence, should be included in the simulations.  When it comes to BC the original definition from RAN1 was changed by RAN4 in order to reach consensus. Furthermore, at low SINR, BC is lost, this means that UEs with UL beam sweep aided BC are relevant to study. As the BC assumption may not hold, the influence on coverage should at least be evaluated from a cell coverage perspective. It could be beneficial if the UE could trigger uplink beam sweeping when the SINR is below a threshold to avoid beam failure. |  |  |
|  |  |  |  |  |

## Higher DMRS density

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

Table 15: Comments on the “Higher DMRS density”

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Company name | LLS gain observed over Rel-15 baseline | Pros. of the proposed scheme | Cons. of the proposed scheme | Other comments |
| vivo |  | Better channel estimation accuracy. | Higher coding rate | The balance between channel estimation accuracy and coding rate should be carefully studied. |
| Samsung |  | Improved performance | Additional gNB receiver complexity | OK to study. Format(s) can be clarified. |
| ZTE |  |  |  | Ok to study whether there is performance gain. |
| CMCC |  |  |  | Higher DMRS density provides a different way from DMRS overhead reduction, both of the two solutions can be studied if the gain is justified |
| CATT |  |  |  | Open to discuss. |
| Nokia/NSB |  | Better channel estimation accuracy. | Higher coding rate | Trade-off between channel estimation accuracy and higher coding rate must be carefully evaluated. Ok to study. |
| Intel |  | Higher DMRS density can help improve channel estimation performance, which is critical at low SNR regime. | It is not clear whether > 4 DMRS symbols are needed for long PUCCH format as it would increase the coding rate and degrade the performance. | Open to discuss |
| Ericsson |  |  |  | OK to further study to see if there’s gain. |
| Huawei, Hisilicon |  | a higher DMRS density in some cases can enable a better channel estimation and improve PUCCH coverage. It’s a tradeoff between DMRS overhead and channel estimation accuracy. |  |  |
| Qualcomm |  |  |  | Low priority |
| SONY |  | Better channel estimation accuracy | Higher coding rate | Study adaptation of DMRS density such that optimum density for channel conditions can be achieved. |
| Apple |  |  |  | Open to discuss |

## A-CSI on PUCCH

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

Table 16: Comments on the “A-CSI on PUCCH”

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Company name | LLS gain observed over Rel-15 baseline | Pros. of the proposed scheme | Cons. of the proposed scheme | Other comments |
| vivo |  |  |  | It seems that URLLC is also discussing the same topic, it can be discussed in URLLC WI. |
| Samsung |  | Unclear | No difference to P/SP CSI reporting on PUCCH or CSI reporting on PUSCH in terms of coverage – not a coverage enhancement issue | Deprioritize |
| ZTE |  |  |  | Should be discussed in Rel-17 URLLC. |
| CMCC |  | CSI report performance can be improved since PUSCH is the bottleneck channel in most cases. |  | Agree with vivo, ZTE |
| CATT |  |  | Not a CE issue. |  |
| Nokia/NSB |  |  |  | Agree with vivo, ZTE, CMCC. |
| Panasonic |  |  |  | Agree with vivo, ZTE, CMCC and Nokia/NSB. |
| OPPO |  |  |  | Deprioritize |
| Intel |  |  | This is more related to URLLC, not coverage enhancement. | Low priority |
| Ericsson |  | Easy to implement and make A-CSI possible to be repeated on long PUCCH. |  | Since A-CSI is a bottleneck identified in the performance evaluation agenda, it should be addressed and prioritized in this study as well. A-CSI here may be particularly focused on in this study while URLLC may focus on common PUCCH enhancement or maybe just for HARQ-ACK. |
| Huawei, Hisilicon |  |  |  | Low priority  Agree with vivo, ZTE, CMCC and Nokia/NSB. |
| Qualcomm |  |  |  | Low priority. Being studied in R17 eURLLC SI. |
| Sharp |  |  | It is unclear to us how it relates to Coverage enhancement for PUCCH. |  |
| Apple |  |  |  | Low priority |

## Symbol-level PUCCH repetition

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

Table 17: Comments on the “Symbol-level PUCCH repetition”

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Company name | LLS gain observed over Rel-15 baseline | Pros. of the proposed scheme | Cons. of the proposed scheme | Other comments |
| vivo |  |  |  | We think symbol level PUCCH repetition have similar performance as (mini-)slot based repetition. |
| Samsung |  | Can utilize all available resources | May require significant complexity increase | OK to study if time allows |
| ZTE |  |  |  | Can be discussed together with 3.2. |
| CMCC |  |  |  | If Type-B like PUCCH repetition is studied, this can be low priority. |
| CATT |  |  | The benefits are questionable. It seems there is channel estimation loss with symbol level repetition as all the DMRS are centralized. |  |
| Nokia/NSB |  |  |  | In our view this should be considered as a lowe-priority alternative to 3.2. |
| Panasonic |  | More number of symbols can be combined coherently without suffering the frequency error and channel variation than slot-level repetition. |  | Should be discussed with time-domain and/or channel estimation enhancement. |
| OPPO |  |  |  | Open for discussion |
| Intel |  |  | For coverage enhancement, it is not clear whether short PUCCH repetition needs to be considered. For instance, for 2-symbol short PUCCH, 7 repetitions are needed to reach same coverage target as 14-symbol long PUCCH. | Low priority |
| Ericsson |  |  |  | Benefit is not clear compared to current PUCCH repetition support. |
| Qualcomm |  |  |  | Low priority |
| Sharp |  | Symbol level repetition can utilize resource in special slots |  |  |
| Apple |  |  |  | Low priority |

## Relay (including sidelink relay)

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

Table 18: Comments on the “Relay (including sidelink relay)”

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Company name | LLS gain observed over Rel-15 baseline | Pros. of the proposed scheme | Cons. of the proposed scheme | Other comments |
| vivo |  |  |  | Do not consider in this SI. |
| Samsung |  |  |  | Deprioritize, might be discussed in Sidelink. |
| CMCC |  |  |  | Do not consider in this SI. |
| Nokia/NSB |  |  |  | Deprioritize. Other AIs, e.g., Sidelink, may be more suitable for discussions on Relay-assisted operations. |
| OPPO |  |  |  | Not study in this SI |
| Intel |  |  |  | Deprioritize. |
| Ericsson |  |  |  | Not in scope of this study. |
| Qualcomm |  |  |  | Low priority |
| SONY |  | Uplink pathloss reduced as UE can transmit to the nearest relay node (or gNB, if closer). SL relay might not increase network deployment cost. | Non-SL relay increases network deployment cost | Can be considered in other SI (e.g. sidelink) |
| Apple |  |  |  | Out of this scope of this SI |

## Reflective arrays

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

Table 19: Comments on the “Reflective arrays”

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Company name | LLS gain observed over Rel-15 baseline | Pros. of the proposed scheme | Cons. of the proposed scheme | Other comments |
|  |  |  |  | Do not consider in this SI. |
| Samsung |  |  |  | Deprioritize, might be discussed in MIMO WI. |
| CMCC |  |  |  | Do not consider in this SI. |
| Nokia/NSB |  |  |  | Agree with Samsung |
| OPPO |  |  |  | Not study in this SI |
| Intel |  |  |  | Deprioritize. |
| Ericsson |  |  |  | Not in scope of this study. |
| SONY |  | Compared to relays, reflective arrays are a lower cost alternative to mitigate shadowing / enhance coverage and can be deployed with a comparably small spec impact, e.g. pilot signals. | There is a network deployment cost, even if that is lower than the cost of deploying relays / small cells. | Can discuss in MIMO WI or other SI |

## Split UCI payload on short and long PUCCH on adjacent S and U slots

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

Table 18: Comments on the “Split UCI payload on short and long PUCCH on adjacent S and U slots”

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Company name | LLS gain observed over Rel-15 baseline | Pros. of the proposed scheme | Cons. of the proposed scheme | Other comments |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |

# Summary of discussion

## Sequence based DMRS-less PUCCH

Benefits of the scheme

* Gain over Rel-15 baseline (3-5 dB gain observed in LLS: ZTE, CMCC, QC, EUROCOM)
* Versatile for any PUCCH resource allocation without the need for more resources such as repetition
* Can benefit from sequences with low cross-correlation
* Can reduce PAPR with low PAPR sequences
* Simple implementation at UE

Concerns:

* Spec impact
* Baseline reference of the observed gain is not clear
* Simulation assumptions not agreed for the LLS

Receiver complexity/latency

* Two diverged views. Some companies think this scheme increases the complexity of gNB receiver. Some companies think this scheme can reduce the complexity of the gNB receiver.

## PUSCH repetition Type-B like PUCCH repetition

Benefits of the scheme

* Latency reduction
* More flexible/efficient UL resource allocation/usage

Concerns:

* The benefit of the scheme to PUCCH coverage enhancement is not clear
* PUCCH repetition cannot improve HARQ-ACK coverage v
* PUCCH repetition impact PUSCH coverage/date rate
* This is also studied in Rel-17 URLLC enhancement. Coordination cross WI is needed

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

Benefits of the scheme

* More flexible indication to improve resource efficiency, avoid collision with PUSCH, being adaptive to UCI payload size

Concerns:

* The benefit of the scheme to PUCCH coverage enhancement is not clear
* DCI overhead for explicit indication
* Implicit indication may already be supported in spec

## Sequence based PF 0/1 with Pi/2 BPSK

Benefits of the scheme

* Lower PAPR can improve coverage

Concerns:

* Inner RB for PF 0/1 can already use 0 MPR. The additional PAPR gain may not be useful
* Has Impact on UE implementation
* PF 0/1 is not bottleneck for PUCCH
* Multiplexing capability may be reduced due to nonorthogonality of Pi/2 BPSK sequences
  + IITH comment back: Note that there are enough orthogonal sequences using pi/2 BPSK to support this transmission. Furthermore, multiplexing is not the preferred way to transmit critical control information especially for extreme coverage scenarios.

## Pre-DFT data-RS multiplexing for PF2 with Pi/2 BPSK

Benefits of the scheme

* DFT waveform for PF2 can reduce PAPR hence improve coverage

Concerns:

* Short PUCCH format coverage enhancement should be deprioritized.

## DMRS bundling for PUCCH

Benefits of the scheme

* Gain over Rel-15 baseline (~1dB gain observed in LLS: VIVO, Intel)
* Improved channel estimation

Concerns:

* Restrictions due to cross slot phase coherence not available at UE

## Compact UCI

Benefits of the scheme

* Code rate reduction can translate into coverage enhancement

Concerns:

* Compact UCI may impact DL performance
* Spec impact

## Freq hopping enhancement for PUCCH

Benefits of the scheme

* Gain over Rel-15 baseline (1~1.5dB gain observed in LLS: VIVO, Intel)
* Frequency diversity gain
* Easy to implement, small spec impact

Concerns:

* The benefit is questionable given large # Rx at gNB and max # of repetition is already 8
* The gain may diminish in small BWP
* Impact to PUSCH with potential PAPR increase on PUSCH due to discontinuous RB allocation

## Short/mini-slot PUCCH repetition

Benefits of the scheme

* Flexibility in placement of PUCCH for repetition

Concerns:

* It is currently studied under Rel-17 URLLC enh.
* No clear motivation to enhance short PUCCH

Comment: this can be merged with the study of type B PUCCH repetition

## Power control enhancement for PUCCH

Benefits of the scheme

* Allow power boost for FDD high power UE or for UE with certain waveform
* Allow different BLER target per UCI type

Concerns:

* The scope is not clear
* Current power control mechanism is sufficient enough.

## Increase maximum # allowed repetitions for PUCCH

Benefits of the scheme

* Gain over Rel-15 baseline (~2 dB gain observed in LLS when double # repetitions : Intel)
* Straightforward extension with minimum spec impact.

Concerns:

* Does not improve HARQ-ACK performance in TDD
* Impact to PUSCH coverage/data rate due to PUSCH dropping when overlap with PUCCH repetitions
* Has limitation/restriction due to TDD UL/DL pattern
* Following current spec, 8 max repetition is enough. No need to increase max # repetitions.

## PUCCH Transmit diversity scheme

Benefits of the scheme

* Gain over Rel-15 baseline (~1 dB gain observed in LLS: CATT)
* Diversity gain

Concerns:

* Does not apply to single Tx UE
* SORTD Double resource. Freq domain precoding cycling increase PAPR

## DMRS overhead reduction

Benefits of the scheme

* Reduce UCI code rate in case of PUCCH repetition

Concerns:

* Increase receiver complexity

Comment: this can be merged into the study of DMRS bundling.

## UE Antenna configuration enhancement for FR2

Majority view is to deprioritize the study of this scheme.

## Higher DMRS density

Benefits of the scheme

* Better channel estimation

Concerns:

* Increase receiver complexity
* Increase UCI code rate

Comment: this can be merged into the study of DMRS bundling.

## A-CSI on PUCCH

Majority view is to deprioritize the study of this scheme under this sub-agenda. It can be discussed in Rel-17 URLLC CSI enhancement.

## Symbol-level PUCCH repetition

Majority view is to deprioritize the study of this scheme.

## Relay (including sidelink relay)

Majority view is to deprioritize or not consider the study of this scheme.

## Reflective arrays

Majority view is to deprioritize or not consider the study of this scheme.

## Split UCI payload on short and long PUCCH on adjacent S and U slots

# References

|  |  |  |
| --- | --- | --- |
| **Tdoc #** | **Title** | **Source** |
| [R1-2005273](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_102-e/Docs/R1-2005273.zip) | Discussion on the potential coverage enhancement solutions for PUCCH | Huawei, HiSilicon |
| [R1-2005300](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_102-e/Docs/R1-2005300.zip) | Discussion on potential approaches and solutions for NR PUCCH coverage enhancement | Nokia, Nokia Shanghai Bell |
| [R1-2005396](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_102-e/Docs/R1-2005396.zip) | Discussion on Solutions for PUCCH coverage enhancement | vivo |
| [R1-2005428](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_102-e/Docs/R1-2005428.zip) | Discussion on potential techniques for PUCCH coverage enhancements | ZTE |
| [R1-2005585](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_102-e/Docs/R1-2005585.zip) | On PUCCH coverage enhancement techniques | Sony |
| [R1-2005725](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_102-e/Docs/R1-2005725.zip) | Discussion on potential techniques for PUCCH coverage enhancement | CATT |
| [R1-2005759](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_102-e/Docs/R1-2005759.zip) | Discussion on PUCCH coverage enhancement | NEC |
| [R1-2005890](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_102-e/Docs/R1-2005890.zip) | Discussion on potential techniques for PUCCH coverage enhancement | Intel Corporation |
| [R1-2006048](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_102-e/Docs/R1-2006048.zip) | Consideration on PUCCH coverage enhancement | OPPO |
| [R1-2006163](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_102-e/Docs/R1-2006163.zip) | PUCCH coverage enhancement | Samsung |
| [R1-2006227](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_102-e/Docs/R1-2006227.zip) | Discussion on the PUCCH coverage enhancement | CMCC |
| [R1-2006246](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_102-e/Docs/R1-2006246.zip) | PUCCH coverage enhancement | InterDigital, Inc. |
| [R1-2006349](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_102-e/Docs/R1-2006349.zip) | Discussion on PUCCH coverage enhancements | Panasonic Corporation |
| [R1-2006457](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_102-e/Docs/R1-2006457.zip) | PUCCH coverage enhancements | IITH, CeWiT, IITM, Reliance Jio, Tejas Networks |
| [R1-2006580](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_102-e/Docs/R1-2006580.zip) | PUCCH coverage enhancement | Sharp |
| [R1-2006614](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_102-e/Docs/R1-2006614.zip) | PUCCH coverage enhancement | Ericsson |
| [R1-2006742](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_102-e/Docs/R1-2006742.zip) | Potential techniques for PUCCH coverage enhancements | NTT DOCOMO, INC. |
| [R1-2006821](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_102-e/Docs/R1-2006821.zip) | Potential coverage enhancement techniques for PUCCH | Qualcomm Incorporated |
| [R1-2006880](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_102-e/Docs/R1-2006880.zip) | Limitations of NR short block-length codes for PUCCH coverage enhancement | EURECOM/Sophia Antipolis |
| [R1-2006893](https://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_102-e/Docs/R1-2006893.zip) | Discussion on potential techniques for PUCCH coverage enhancement | WILUS Inc. |