**3GPP TSG RAN WG1 #104-e R1- 2101813**

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

**Agenda item:** 8.8.2

**Source:** Moderator (Qualcomm)

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

**Document for:** Discussion/Decision

# Introduction

In this document, a summary of companies’ proposals for PUCCH coverage enhancement is provided.

# Dynamic PUCCH repetition factor indication

## Scope of dynamic PUCCH repetition factor indication

Based on the WID, one of the objectives of this agenda item 8.8.2 is to “specify signaling mechanism to support dynamic PUCCH repetition factor indication”. One question was raised in [[R1-2101523](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104-e/Docs/R1-2101523.zip)][ [R1-2100400](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104-e/Docs/R1-2100400.zip)][[R1-2101480](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104-e/Docs/R1-2101480.zip)] regarding the scope of dynamic PUCCH repetition factor indication. Specifically, the question is that whether dynamic PUCCH repetition factor indication should be applied to PUCCH does not have corresponding DCI, such as P-CSI, SP-CSI, SR, HARQ-ACK for SPS PDSCH. Companies are welcome to add your answer to this question in the following table.

**Question: Whether dynamic PUCCH repetition factor indication can be applied to a PUCCH does not have corresponding DCI, such as P-CSI, SP-CSI, SR, HARQ-ACK for SPS PDSCH?**

|  |  |
| --- | --- |
| **Company name** | **Answer** |
| Samsung | No. The reasons for dynamic repetitions is to adjust to payload variations and to variations in number of symbols of the PUCCH resource. Those reasons do not exist for the listed cases. |
| CATT | For HARQ-ACK for SPS PDSCH, our feeling is that it is similar to the dynamically indicated HARQ-ACK for normal PDSCH, at least from the signaling perspective, i.e. it can be indicated by the activated/release DCI. It may be natural to apply the dynamic PUCCH repetition factor indication to HARQ-ACK for SPS PDSCH.  For the semi-static UCI, i.e. P-CSI, SP-CSI and SR, it may be not necessarily to have the dynamic PUCCH repetition factor indication. For SR, only one RB is needed in frequency domain and the resource consumption is not an issue even with large repetition number. gNB can configure the repetition number with a conservative manner in order to guarantee the coverage. For P-CSI and SP-CSI, if the coverage becomes a problem in certain case, gNB can trigger an A-CSI reporting.  Although we slightly prefer only apply to a PUCCH carrying HARQ-ACK for SPS PDSCH, we are open to discuss the other UCI type. |
| China Telecom | We think it may be pretty hard to perform dynamic PUCCH repetition for a PUCCH does not have corresponding DCI. But we are open to discuss it. |
| Spreadtrum | There are also coverage issues for PUCCH without corresponding DCI, thus we think dynamic PUCCH repetition factor indication should be applied for those PUCCHs. |
| Xiaomi | How to dynamically indicating a PUCCH repetition factor for the PUCCH without corresponding DCI is a problem. We are open to discuss the other UCI type. |
| ZTE | If repetition factor is configured per PUCCH resource, these resources can be also applied other UCI types. While we don’t know how to make it dynamic for indication of PUCCH without DCI. |
| Panasonic | We think to realize dynamic PUCCH repetition factor indication without having corresponding DCI is difficult. The discussion could be lower priority. |
| WILUS | Dynamic PUCCH repetition factor indication can be applied to a PUCCH have corresponding DCI, such as HARQ-ACK for dynamically scheduled PDSCH or A-CSI. For the HARQ-ACK for SPS PDSCH, repetition factor can be indicated via activation DCI. |
| Intel | We do not think this would be applied for a PUCCH without corresponding DCI. In other words, this only applies for dynamic HARQ-ACK. |
| Vivo | No. It is not necessary to discuss the PUCCH repetition for periodic and semi-persistent transmission, and it is out of the WID scope. |
| OPPO | We can focus on supporting dynamic indication of those “dynamic” PUCCH. |
| Lenovo, Motorola Mobility | We do not see the need of dynamic PUCCH repetition factor indication for PUCCH without a corresponding DCI. |
| Ericsson | Since CSI payloads were the ones that were shown to have the worst PUCCH coverage during the study, support for dynamic PUCCH repetition for those formats makes sense to us, although this depends on the progress of A-CSI on PUCCH in URLLC. Irrespective of this, like ZTE, we think that if the PUCCH repetition factor is included in the PUCCH resource definition, the resource and its repetition can be used according to the UCI type that the resource is provided for. For example, different CSI report configurations could have different repetition factors (in the different PUCCH resources).  Overall, we are not sure how to answer the question 😊. We expect that dynamic indication uses DCI, and that indicating PUCCH resource that contains a repetition factor in DCI is considered to be dynamic PUCCH repetition factor indication. So while we would hope that dynamic CSI repetition factors can be supported, they should use DCI. If this dynamic repetition is not supported for CSI, a configured repetition value for the PUCCH resource that carries CSI can still be used for CSI or perhaps UCI types like SR and HARQ-ACK for SPS PDSCH. |
| Qualcomm | Yes. We think that the main reasons for having dynamic PUCCH repetition factor can also apply for periodic CSI report and Ack/Nack feedback for SPS. The reasons for desiring dynamic PUCCH repetition include changes of channel conditions and interference levels and also beam switching. This issue is more important in FR2 (because of more drastic interference fluctuations). It should be noted that based on the link budget evaluation, PUCCH with larger payloads (which in many cases are because of carrying the L1 report) are more vulnerable for coverage. Also, reliability of the L1 report is essential for ensuring the performance of the whole system (especially for FR2).  Another issue (especially for FR2) is that switching beams may also affect the appropriate repetition factor for different PUCCHs. Therefore, it is useful to be able to dynamically change the repetition factor of the affected PUCCHs, whether implicitly (based on the same signaling that indicates beam switching) or by another signaling (e.g. another DCI). |
| Nokia/NSB | No. We support the majority view that “dynamic indication of number of repetitions” means that the information for selecting the number of PUCCH repetitions should be included in the scheduling DCI. |
| NTT DOCOMO | We are fine to discuss for all UCI types, though some of the indications may be semi persistent. |
| Sharp | Dynamic PUCCH repetition factor indication is not required to be applied to the PUCCH that does not have corresponding DCI because a repetition factor for P-CSI/SP-CSI should be configured by RRC and these are identified as low priorities. For HARQ-ACK for SPS PDSCH, repetition factor can be indicated at activation of SPS by DCI. |
| Apple | No, we don’t see benefit that justifies dynamically change of number of PUCCH repetition for example for P-CSI. |
| ETRI | Our understanding is that a dynamic indication does not involve for periodic CSI and SR. For other UCI types, the dynamic indication can be applied for PUCCH repetition factor. |
| LG | No, justification for dynamic repetition for PUCCH without corresponding DCI should be preceded. |

## Options for dynamic PUCCH repetition factor indication

Based on the input from all companies, there are three options to support the signaling of dynamic PUCCH repetition factor.

Option 1 (without DCI enhancement): Enhance RRC signaling to allow configuration of PUCCH repetition factor per PUCCH resource. Dynamic PUCCH repetition factor indication is effectively achieved by reusing the “PUCCH resource indicator” field (without increase # bits of it) in DCI.

Supporting companies: Huawei/HiSi, ZTE, VIVO, IDC, Intel, Ericsson, Docomo, Sharp, ETRI, Wilus, CATT, CT, LG, CMCC, Xiaomi, Panasonic, [Apple?], Spreadtrum

Option 2 (with DCI enhancement): Introduce a new field or increase the number of bits of existing field (e.g., PRI) in DCI for PUCCH repetition factor indication.

Supporting companies: Nokia, QC, Oppo, Samsung (with different configurations), CATT, CT, Apple, LG, CMCC, Xiaomi, ETRI, Spreadtrum

Option 3: Without increasing the number of bits of “PUCCH resource indicator”, re-interpret this field such that a value of this field is mapped to a combination of PUCCH resource index and repetition factor.

Supporting companies: Lenovo, Motorola Mobility

Based on FL initial assessment, the pros and cons of the three options can be summarized in the below table.

|  |  |  |
| --- | --- | --- |
|  | Pros | Cons |
| Option 1 | No DCI size increment  Applicable to fallback DCI | Does not apply to P/SP-CSI or HARQ-ACK for SPS PDSCH  Medium flexibility |
| Option 2 | Maximal flexibility  With DCI enhancement, it (potentially) can be applied to P/SP-CSI or HARQ-ACK for SPS PDSCH | Increased DCI size/new DCI field  Not applicable to fallback DCI |
| Option 3 | FFS | Least flexibility because the number of repetitions for each resource index is hardcoded in spec |

Based on the pros and cons of the above options, also considering the number of supporting companies, the following is proposed.

**Proposal 1: Down select from the following two options to support dynamic PUCCH repetition factor indication.**

* **Option 1 (without DCI enhancement): Enhance RRC signaling to allow configuration of PUCCH repetition factor per PUCCH resource. PUCCH repetition factor is implicitly indicated by DCI via reusing the “PUCCH resource indicator” field (without increase # bits of it) and/or starting CCE index** **of DCI.**
  + **FFS: RRC signaling enhancement details**
* **Option 2 (with DCI enhancement): PUCCH repetition factor is explicitly indicated by DCI, e.g., introduce a new field or increase the number of bits of an existing field (e.g., PRI) in DCI for PUCCH repetition factor indication.**

Companies are welcome to provide comments to the above proposal in the following table.

|  |  |
| --- | --- |
| **Company name** | **Comments** |
| Samsung | Option 2 is a straightforward way to account for the variable number of symbols and UCI payloads in the number of repetitions.  It is not correct that Option 1 does not require DCI size increase – it is not for free. For example, if the number of repetitions is not included in the PUCCH resource, the PRI can have fewer bits (and the additional bits can be used to indicate the repetitions).  In addition to not mixing functionalities, another important advantage of Option 2 vs. Option 1 is that an adjustment of the number of repetitions to the UCI payload is fully flexible – not so if the repetitions are part of the PUCCH resources where many-to-one mapping exists between UCI payloads and PUCCH resource. |
| CATT | We are fine with the proposal. |
| China Telecom | Support this proposal. Both option 1 and option 2 are acceptable for us. |
| Spreadtrum | We support this proposal and both options are fine. |
| Xiaomi | We are general fine with the proposal. But for proposal 2, we think it is better to reuse the existing field in DCI rather than introducing a new field or increasing the number of bits of an existing field, we suggest the 2bits power control field DCI 1\_0/1\_1/1\_2 can be reused for the PUCCH repetition factor indication. Because PUCCH repetition schemes are mainly applicable for coverage enhancement for cell-edge users who already configured with full transmit power. |
| ZTE | Our preference is Option 1 without DCI enhancement. But, if we want to have a fair comparison with Option 2, it may be better not to preclude the possibility of enhancing DCI for Option 1 now. |
| Panasonic | We are fine with the proposal 1. |
| WILUS | We support the FL proposal. Additionally, if number of repetition for PUCCH is dynamically indicated, frequency hopping issue proposed in our contribution [[R1-2101682](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104-e/Docs/R1-2101682.zip)] can be further studied. |
| Intel | We are fine with the proposal. For Option 1, it may be more accurate to also add PRI in the DCI and/or starting CCE index for PUCCH repetition factor determination. |
| Vivo | We support the FL proposal. And Option 1 is preferred.  Introducing a new DCI field should be avoided, since a larger DCI size in addition to existing field will bring about degraded PDCCH performance. |
| OPPO | Selection of the two is ok. Please not the PRI scheme may impact the PUCCH resource collision mechanism and some of the resource is determined by CCE, which will make the gNB hard to indicate a proper PUCCH resource. |
| Lenovo, Motorola Mobility | Option 3 listed above is similar to option 1 in our understanding. With option3, the intention was not to hardcode the repetition number for PUCCH resource, but rather have it configurable by RRC and indicated by the PRI field.  Therefore, we are fine to support option 1 in the moderator’s proposal |
| Ericsson | We think Option 1 should be to allow configuration of PUCCH repetition, and not to constrain the bit field size, in order to have a fair comparison with Option 2. We support such a modified Option 1.  Comparing to Option 2, we observe that jointly encoding parameters reduces overhead, or has at least the same amount of overhead as independently coding the parameters. Furthermore, it is more flexible to allow more combinations of parameters than to separately encode them. So Option 1 is both more efficient and more flexible than option 2.  We also observe that jointly encoded parameters were used for dynamic PUSCH indication in Rel-16, where the TDRA table encodes the repetitions. So encoding repetition values via PRI follows Rel-16 principles.  Lastly, the reuse of a field is more backward compatible from a PDCCH reception viewpoint, since the DCI fields can be parsed in the same way and the DCI size is the same. |
| Qualcomm | We are fine with the proposal. |
| Nokia/NSB | Support the FL’s proposal. |
| NTT DOCOMO | We are fine with the proposal, and we prefer Option 1. |
| Sharp | We have a concern on applicability to fallback DCI for Option 2. |
| Apple | We are fine with the proposal under a change in Option 1, where RRC indication is not limited to PUCCH resource is RRC configured with number of repetitions. There could be other methods, yet under RRC indication of number of repetitions… |
| InterDigital | We are ok with the proposal and our preference is Option 1. |
| CMCC | We are fine with the proposal, and option 1 is slightly preferred |
| Huawei, HiSilicon | Our preference is Option 1. But we are fine with the proposal. |
| ETRI | Agree with the proposal. |
| LG | Fine with proposal but further discussion is needed for same level of understanding about options. For option 1, it can be achieved by adding repetition factor to the PUCCH resource set table and reusing PRI. There are several alternatives for option 2. For example:  1. A dedicated new field DCI can be introduced only for the repetition number of PUCCH.  2. The additional PUCCH resource sets with repetition number can be introduced, or the extension of PUCCH resource sets for repetition number can be considered. Either way, enhanced DCI for PRI is necessary.  3. Without modifying existing PUCCH resource set table, a new PUCCH resource set table with repetition can be introduced and new bit field of DCI can be introduced to indicate which table should be used.  We are open to detailed discussion. |

# DMRS bundling across PUCCH repetitions

The second objective of this agenda item is to “specify mechanism to support DMRS bundling across PUCCH repetitions.” Under this objective, a few topics are addressed in companies’ contributions. The topics are summarized as below.

## Prerequisite for DMRS bundling across PUCCH repetitions

Several prerequisites are proposed by different companies. The prerequisites include at least the following

* Same transmission power across PUCCH repetitions
* Same frequency resource allocation across PUCCH repetitions
* No TA adjustment across PUCCH repetitions
* No Tx spatial filter change across PUCCH repetitions
* No time gap across PUCCH repetitions

Many companies expressed that RAN1 should aim to harmonize the Prerequisite of DMRS bundling for PUCCH and PUSCH.

FL’s initial assessment is that RAN1 could wait for RAN4 reply LS to decide what RAN1 need to do with those prerequisites.

[[R1-2101523](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104-e/Docs/R1-2101523.zip)] proposed to study gNB assisted wideband phase compensation (single scalar estimation) to enable bundling across noncontiguous slots. Companies are encouraged to provide feedback regarding this proposal in the following table.

|  |  |
| --- | --- |
| **Company name** | **Comments on the proposal “to study gNB assisted wideband phase compensation (single scalar estimation) to enable bundling across noncontiguous slots”** |
| Samsung | We don’t think this needs to be studied because of the additional UE complexity, DL overhead, and likelihood of no gains given that the size of the DMRS bundling window will be anyway limited by the gNB frequency clock error. |
| CATT | It seems the gNB assisted wideband phase compensation is a kind of gNB implementation. Could Ericsson elaborate a little bit for better understanding? For example, what is the specification impact? |
| Xiaomi | Open to discuss it. |
| ZTE | We are fine to discuss, but whether to study or not may need more input maybe in the next RAN1 meeting. |
| Intel | This needs further investigation on the feasibility. We could also ask RAN4 for input on this. |
| Vivo | Wideband phase compensation can be considered if gNB is able to estimate the phase difference across PUCCH/PUSCH transmissions in implementation. However, we are not sure how to model the phase change if there is gap between PUSCH/PUCCH transmission. We wonder whether the feasibility of this compensation also need to be confirmed by RAN4? |
| OPPO | Unclear the needed specification impact of the scheme. Generally, the channel estimation should be allowed even with the current spec. |
| Lenovo, Motorola Mobility | Open to further discuss this |
| Ericsson | Thanks to the feature lead for capturing our proposal. To reiterate, our hope is to get better applicability of cross-slot channel estimation, since it is not likely to be so useful in heavy TDD DL:UL configurations, or in general where back-to-back transmission is infeasible.  To reply to some of the comments so far:  @Samsung: Thanks for the detailed comment. Perhaps we’re not on the same page: it is not our intention to signal a phase correction on the downlink, but to estimate the phase error at the gNB.  @CATT: Yes, gNB implementation is estimating a wideband phase correction across slots. The spec impact may be according to how UE capability works and/or RAN4 requirements & testing. The UE will need to transmit such that a one (or a small number) of phase corrections across the carrier and between the slots will be sufficient for the gNB to coherently combine the slots.  @Intel & vivo: Agree that asking RAN4’s view would be quite helpful, since whether the phase errors can be wideband is definitely more in their area of expertise than ours.  @OPPO: True, gNB could try to do so, but it our understanding there is no guarantee that UEs will transmit such that a wideband phase correction can be used to combine slots. |
| Qualcomm | While we understand the motivation, we are concerned that this pursuing this approach may lead to introducing two different sets of requirements and conditions for phase continuity at the UE. We are also not sure whether this relaxation benefits a multi-tx UE that may have antenna virtualization. On the whole, even with this relaxation, since the UE still has to make modifications to several other processes (timing adjustments, freq offset corrections, calibrations, etc), we don’t think this relaxation alone makes a significant impact to the UE. We are therefore not too keen on pursuing this approach. |
| Nokia/NSB | We share the same view as Samsung that this case would need assessment in many aspects and RAN1 should not consider it directly in a WI with limited TU as Coverage Enhancement without carefully studying the benefit and impacts. Indeed, as also pointed out by CATT, if the estimation at the gNB does not require any additional signaling from UE, then it can be considered as gNB implementation. In contrast, if additional signaling is needed from UE, it introduces more complexity and overhead. |
| Apple | Share same view as FL (RAN1 could wait for RAN4 reply) |
| InterDigital | Our preference is to use the RAN4 reply for R1-2009784 as the starting point to discuss DMRS bundling. This topic should be discussed/studied at lower priority since this is the case when the UE cannot maintain phase continuity (i.e,. the UE cannot satisfy the conditions indicated by RAN4). We agree with Nokia and CATT that this can be gNB implementation issue. We should specify DMRS bundling based on the assumption that the UE satisfies the feasibility condition for maintenance of power/phase continuity. |
| ETRI | We are open to discuss after RAN4 LS. |
| LG | It seems rather NW implementation to us. Further clarification for motivation of study is needed. |

[[R1-2100460](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104-e/Docs/R1-2100460.zip)] proposed that a UE can signal to NW when the UE can ensure phase continuity for UL transmission across multiple occasions, and how long UE can maintain the phase continuity. Companies are encouraged to provide feedback regarding this proposal in the following table.

|  |  |
| --- | --- |
| **Company name** | **Comments on the proposal of “a UE can signal to NW when the UE can ensure phase continuity for UL transmission across multiple occasions, and how long UE can maintain the phase continuity”** |
| Samsung | We don’t think such a detailed UE capability report is needed. The proposal is also unnecessary at the moment. It can be revisited once the design for DMRS bundling has progressed. |
| CATT | Open to discuss. |
| Xiaomi | We agree the phase continuity should be guaranteed for DMRS bundling, but whether it belongs to a UE capability and needs UE report should be further discussed. With channel condition varying all the time, how long UE can maintain the phase continuity is difficult to predict. |
| ZTE | Agree with Samsung. Such detailed UE capability report is not needed. Depending on the RAN4 reply, the conditions may be met by gNB scheduling without requiring additional UE capability. |
| Intel | It would be good that we can ask RAN4 for input. |
| Vivo | In our opinion the capability reporting is necessary. We can discuss whether the capability is needed after RAN4 feedback. |
| OPPO | We need further discuss, there is not sign of conclusion for which indication is needed. |
| Lenovo, Motorola Mobility | Open to further discuss this |
| Ericsson | While we understand that the intention is to avoid error conditions where the gNB combines slots that do not support phase continuity, indicating when phase continuity can be maintained in a frequent way may make it hard for gNB to get any coverage gain from cross-slot and may make scheduling the UE more difficult. We are open to consider this further however, especially as we get more feedback from RAN4 on phase continuity works. |
| Qualcomm | How long a UE can maintain phase coherence is an important consideration. Some form of capability signaling is required. This needs further discussion but can be handled once more basic design details get finalized. |
| Nokia/NSB | Agree with Samsung and ZTE. Such signaling is not desirable especially in coverage shortage. |
| NTT DOCOMO | We are open for the discussion, and the UE capability may be discussed later stage. |
| Sharp | How long UE can maintain the phase continuity and whether it is required to be reported are depended on RF circuit and should be discussed in RAN4. |
| Apple | Again RAN4 input is needed |
| InterDigital | Our preference is to use the RAN4 reply for R1-2009784 as the starting point to discuss DMRS bundling. We should specify DMRS bundling based on the assumption that the UE satisfies the feasibility condition for maintenance of power/phase continuity. |
| CMCC | Open for discussion. Our initial thinking is some simplified expression of UE capability about the phase continuity or how long the joint channel estimation could be maintained could be supported. Though this is more dependent on RAN4’s reply. |
| Huawei, HiSilicon | Such UE capability can be discussed after concrete design is done. It seems too early to have this proposal. |
| ETRI | We understand the motivation and are fine to discuss. |
| LG | We also think RAN4 input is needed and it is desirable to discuss UE capability in later stage. |

## Interaction between DMRS bundling and intra/inter slot freq hopping

For the interaction between DMRS bundling with inter-slot and intra-slot frequency hopping, 9 companies (Vivo, ZTE, OPPO, Xiaomi, Intel, CMCC, Apple, Panasonic, CATT) propose to study or support inter-slot frequency hopping pattern enhancement with DMRS bundling across PUCCH repetitions.

For intra-slot frequency hopping enhancement with DMRS bundling across PUCCH repetitions, [[R1-2100747](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104-e/Docs/R1-2100747.zip)] proposes to support it, while [[R1-2101129](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104-e/Docs/R1-2101129.zip)] is against to support it.

Based on the input from companies on this topic, the following FL proposal is made

**Proposal 2: Subject to the prerequisite of DMRS bundling for PUCCH repetitions, support inter-slot frequency hopping pattern enhancement for PUCCH repetitions with DMRS bundling.**

* **FFS: details in inter-slot frequency hopping pattern enhancement, e.g., additional frequency hopping patterns than Rel-16.**
* **~~FFS: intra-slot frequency hopping enhancement for PUCCH repetitions with DMRS bundling.~~**

Companies are welcome to provide comments to the above proposal in the following table.

|  |  |
| --- | --- |
| **Company name** | **Comments** |
| Samsung | OK in general. The wording can be improved (e.g. there is no “enhancement”, only additional FH pattern(s) than in Rel-16) but that can be discussed later. |
| CATT | Support. |
| China Telecom | Support this proposal. |
| Xiaomi | We support it. |
| ZTE | Fine with the proposal. |
| Panasonic | We support proposal 2. |
| WILUS | We support the FL proposal. |
| Intel | We are fine with the proposal in principle. It may be good to align the terminology used for PUSCH coverage enhancement, e.g., support inter-slot frequency hopping with inter-slot bundling. |
| vivo | **Inter**-slot frequency hopping pattern enhancement can be considered.  **Intra**-slot frequency hopping with DMRS bundling is not included in WID scope even for PUSCH DMRS bundling. For PUCCH DMRS bundling for **intra**-**slot** frequency hopping, additional mechanism, compared to inter-slot frequency hopping with DMRS bundling for PUSCH enhancement, should be avoided. |
| OPPO | Agree. |
| Lenovo, Motorola Mobility | Support the proposal |
| Ericsson | Support the FL proposal, although the benefit of intra-slot seems questionable. |
| Qualcomm | We are okay to study inter-slot freq. hopping. Intra-slot freq hopping appears incompatible with DMRS bundling and does not need to be studied further here. Revised proposal:  **Proposal 2: Subject to the prerequisite of DMRS bundling for PUCCH repetitions, support inter-slot frequency hopping pattern enhancement for PUCCH repetitions with DMRS bundling.**   * **FFS: details in inter-slot frequency hopping pattern enhancement.** * **~~FFS: intra-slot frequency hopping enhancement for PUCCH repetitions with DMRS bundling.~~** |
| Nokia/NSB | We are fine with the FL’s proposal in principle. |
| NTT DOCOMO | We are open for the discussion, and the UE capability may be discussed later stage. |
| Sharp | Support. |
| Apple | Support FL’s proposal with dropping second FFS (as also mentioned by QC) |
| InterDigital | We support the proposal. |
| CMCC | Generally fine with the updated proposal from FL. |
| Huawei, HiSilicon | OK |
| ETRI | Support the proposal. |
| LG | Fine with FL’s proposal |

## Signalling mechanism to enable DMRS bundling across PUCCH repetitions

Two open issues are identified in the area of signaling mechanism to enable DMRS bundling across PUCCH repetitions.

**This first issue is how to enable DMRS bundling across PUCCH repetitions.** Several companies address this issue in their contributions and their view are summarized as below.

* Xiaomi: via dynamic signaling
* Interdigital: via semi-static configuration
* Panasonic: via UE specific configuration
* QC: via RRC configuration on per PUCCH resource basis

So far, the views are quite diverged. Companies are welcome to provide comments and solution to this open issue.

|  |  |
| --- | --- |
| **Company name** | **Comments** |
| Samsung | UE specific configuration seems sufficient but OK to discuss further whether or not there is any need for DCI-based indication. |
| CATT | This issue is related to the second issue. Considering we are discussing how to single/configure DMRS bundling duration/size, do we really need a separate indication to enable DMRS bundling across PUCCH repetitions？  If gNB signal/configure a DMRS bundling duration/size, the DMRS bundling across PUCCH repetitions is automatically enabled. |
| China Telecom | Similar mechanism of PUSCH can be considered. |
| Xiaomi | Because the PUCCH repetition factor is dynamic indicated and the number of PUCCH repetition for each PUCCH format can be change flexibly. So correspondingly, it is better to support enabling DMRS bundling across PUCCH repetitions via dynamic signaling. |
| ZTE | Both semi-static configuration or dynamic indication can be considered at this stage. |
| Panasonic | In eMTC. the period of joint channel estimation and the period of inter-slot frequency hopping are cell level configuration. However, in NR, it would be difficult to use cell level configuration as more flexibility would be required. Therefore, at least UE-specific configuration is required. Dynamic indication can be further considered. |
| Intel | For enabling DMRS bundling, our view is that this can be configured by UE specific RRC signalling. |
| vivo | DMRS bundling configured on PUCCH resource via RRC seems simple and straightforward. |
| OPPO | Further discussion. |
| Lenovo, Motorola Mobility | UE-specific configuration should be supported. Further discussion could be whether dynamic or semi-static signaling is needed |
| Ericsson | Need further discussion. It is unclear at this stage why we would need to turn bundling on and off in a rapid manner if the UE can maintain relative phase without e.g. extra power or computational resource. So, unless there are clear benefits to the UE, we expect a semi-static rate of signaling is sufficient. However, if there is some need to bundle on a per resource basis, then selecting between resources with bundling on and off via PRI should not be precluded. |
| Qualcomm | For now, we prefer to keep this open, and allow both semi-static or dynamic indication. We can revisit this once design directions become clear. |
| Nokia/NSB | We share the same view with Samsung, Panasonic and Intel that UE specific RRC signaling should be sufficient. |
| NTT DOCOMO | We are open for the discussion, and we may follow the mechanism discussed in 8.8.1.3. |
| Sharp | It should be similar to design principle of PUSCH. |
| Apple | Let’s keep it open until further progress is made in PUSCH (a unified design is preferred) |
| InterDigital | We are open to discuss these alternatives. Our preference is to support semi-static configuration. |
| CMCC | This depends on the restrictions of DMRS bundling/joint channel estimation. Depending on how long could the DMRS bundling could be maintained, we could decide whether the dynamic indication should be supported. Currently we do not see strong motivation to active or de-active the DMRS bundling dynamically. At least RRC configuration could be considered. we are open for more views. |
| Huawei, HiSilicon | UE specific signaling is preferred as the same as Joint channel estimation for PUSCH. |
| ETRI | Enabling bundling can be semi-statically indicated. We are open to discuss dynamic indications. |
| LG | At least semi-static configuration is necessary in our understanding. We are open for additional study whether the dynamic indication is needed or not. |

**The second issue is how to signal/configure DMRS bundling duration/size.** Several companies address this issue in their contributions and their view are summarized as below.

* VIVO: implicitly derived based on TDD configuration
* Xiaomi: via configure on per PUCCH format basis
* Interdigital: via an indication of bundling group index
* Panasonic: via UE specific configuration
* LG: whether allow multiple bundling size for an aggregated PUCCH repetitions
* QC: via signaling of a bundling window

So far, the views are quite diverged. Companies are welcome to provide comments and solution to this open issue.

|  |  |
| --- | --- |
| **Company name** | **Comments** |
| Samsung | FFS.  Need for configuration of a bundling window should be further discussed. |
| CATT | Open to discuss. |
| China Telecom | Similar mechanism of PUSCH can be considered. |
| Xiaomi | Different PUCCH format has different symbol length and number of repetitions, so we think DMRS bundling duration/size should be differentiated among PUCCH format. |
| ZTE | We are not sure why we need to explicitly define a DMRS bundling size. For instance, if a UE can maintain phase continuity across consecutive repetitions, then DMRS bundling could be applied among all repetitions (if there is no FH). Whether and how gNB perform the DMRS bundling is up to gNB implementation. |
| Panasonic | At least UE-specific configuration is required. Dynamic indication can be further considered. |
| Intel | Our view is that DMRS bundling size can be either configured by higher layers or implicitly determined by the number of repetitions for PUCCH. |
| vivo | DMRS bundling size should be indicated by NW. However, it is possible that the consecutive/applicable slots are less than the DMRS bundle size in TDD band. In this case, TDD slot format configuration should also be considered in bundling size determination. |
| OPPO | We prefer configuration, but it can be discussed. |
| Lenovo, Motorola Mobility | UE-specific configuration should be supported. Further discussion could be whether the duration is semi-statically or dynamically configured |
| Ericsson | While we can understand that UEs may need to adjust transmissions at the slot boundary, we’d like to better understand the need to define DMRS bundling durations. Back to back transmissions of repeated PUCCHs do not seem too likely, and so we wonder how much needs to be specified for PUCCH. Similarly, TDD may have less of a need for a defined bundling window if back-to-back transmission is required to maintain phase coherence. On the other hand, if some window is defined for PUSCH, that can be considered in the PUCCH design. |
| Qualcomm | Agree that some form of bundling size or duration needs to be indicated to the UE by the NW so that the UE knows how long it is expected to bundle DMRS. Exact details on how to signal this can be discussed as additional design details emerge. |
| Nokia/NSB | Unlike the joint channel estimation for PUSCH where the joint channel estimation is not limited to only PUSCH repetitions, the joint channel estimation for PUCCH is limited to PUCCH repetitions only. Therefore, we don’t see the need to define a window in this case if the UE can keep the joint channel estimation requirements across PUCCH repetitions. |
| NTT DOCOMO | We agree to specify the configuration, and we may follow the mechanism discussed in 8.8.1.3. |
| Sharp | It should be similar to design principle of PUSCH. |
| Apple | Same comment as before, but in general we think the window length should be (at most) limited to consecutive repetition duration on the same hop |
| InterDigital | We are open for discussion. Our preference is to have a mechanism that can support multiple DMRS bundles. |
| CMCC | The bundle size should at least consider the limitation of TDD uplink and downlink configurations. |
| Huawei, HiSilicon | Prefer the same design principle of joint channel estimation for PUSCH because the same UE conditions are supposed to be applied for both PUSCH and PUCCH |
| ETRI | We prefer semi-static configuration. |
| LG | Fine with discussion and support allowing multiple bundling size for an aggregated PUCCH repetitions, however we are open to discuss. |

Based on companies input, the following proposal is made.

**Proposal 3: Support enabling PUCCH repetitions with DMRS bundling via RRC configuration.**

* **FFS: the configuration is pre UE or per PUCCH resource.**
* **FFS: whether additional dynamic signaling is needed to enable/disable PUCCH repetitions with DMRS bundling**
* **FFS: necessity of additional signaling/configure of DMRS bundling duration/window and associated size**

Companies are welcome to provide comments to the above proposal in the following table.

|  |  |
| --- | --- |
| **Company name** | **Comments** |
| LG | Fine with FL’s proposal. |
| CATT | Fine with P#2 and P#3. For P#3, there is a typo in the first sub-bullet, it should be ‘per UE’.  For P#1, the intention of the highlight part is for PUCCH format#1? If so, we are OK with it but it should be moved to a sub-bullet.  **Proposal 1: Down select from the following two options to support dynamic PUCCH repetition factor indication.**   * **Option 1 (without DCI enhancement): Enhance RRC signaling to allow configuration of PUCCH repetition factor per PUCCH resource. PUCCH repetition factor is implicitly indicated by DCI via reusing the “PUCCH resource indicator” field (without increase # bits of it) ~~and/or starting CCE index~~** **of DCI.**   + **For PUCCH format#1, starting CCE index should be used together with PRI.**   + **FFS: RRC signaling enhancement details** * **Option 2 (with DCI enhancement): PUCCH repetition factor is explicitly indicated by DCI, e.g., introduce a new field or increase the number of bits of an existing field (e.g., PRI) in DCI for PUCCH repetition factor indication.** |
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## Interruption/prioritization between DMRS bundled PUCCH repetitions and other DL/UL channels

[[R1-2100460](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104-e/Docs/R1-2100460.zip)] mentioned PUCCH repetitions with DMRS bundling may be interrupted by other transmissions/procedures, and whether and how to ensure phase continuity in these cases should be further studied. The interruptions could occurs when an PUCCH transmissions is cancelled by SFI, CI or higher priority transmissions. A PUCCH transmission can also be impacted by UL transmission in another serving cell, when intra band CA is configured.

[[R1-2101398](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104-e/Docs/R1-2101398.zip)] identified that following the current specification, a PUCCH repetition occasion within a bundle of repetitions with DMRS bundling may be dropped, e.g. if another overlapping PUCCH has a UCI type with a higher priority, as mentioned above. Subsequently, the phase continuity will be lost for the first PUCCH with DMRS bundling. It is proposed in [[R1-2101398](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104-e/Docs/R1-2101398.zip)] If DMRS bundling is supported, specify conditions under which a PUCCH with DMRS bundling overlapping in one (or more) occasions with a second PUCCH and yet UE is able to perform joint channel estimation across all repetitions.

So far, only two companies provided views on this issue. FL would like to collect more input on this issue before moving forward. In the table below, companies are encouraged to provide feedback on UE procedures to handle interruption/prioritization between DMRS bundled PUCCH repetitions and other DL/UL channels.

|  |  |
| --- | --- |
| **Company name** | **Comments on UE procedures to handle interruption/prioritization between DMRS bundled PUCCH repetitions and other DL/UL channels** |
| Samsung | RAN4 input may be required about whether or not the UE can maintain phase continuity if the UE only suspends an ongoing transmission. Further, it is not clear whether any specification support is required for such cases. The issue can be deprioritized for now and be discussed further next time. |
| CATT | For UL CI, there should be no issue as UL CI cannot cancel a PUCCH transmission.  For the other two cases mentioned above, a general comment is that what is the difference from the non-continuous PUCCH transmission? If the RAN4 requirement and all the aforementioned factors are satisfied, the cancellation case seems same as the other general cases. |
| ZTE | Similar question as CATT. |
| Panasonic | Although the detailed condition is up to RAN4 discussion/reply, our expectation is at least when the transmission power is not changed across PUCCH repetitions, phase continuity would be kept with some exceptions such that there is no DL reception and gap between PUCCH transmissions is not very long. |
| Intel | It would be good to wait for the LS reply from RAN4 first before we discuss this issue |
| vivo | RAN4 discussion results may be required before detailed discussion.  We think it may be better for RAN1 to identify the potential cases for which the phase continuity can not be maintained, e.g. procedures that may impact UE transmission power, etc., in current stage. |
| Lenovo, Motorola Mobility | Suggest waiting for RAN4 LS reply on conditions for maintaining phase continuity before discussing this issue. |
| Ericsson | Similar view as other companies; suggest to keep this issue in mind for next meeting. |
| Qualcomm | We agree that clear rules on prioritization and bundling interruption are required. This discussion can however be postponed until a basic DMRS bundling framework is agreed. |
| Nokia/NSB | Same view as CATT. |
| Sharp | DMRS bundling can be applied when there is no DL reception between PUCCHs. |
| Apple | We share similar view as QC. |
| InterDigital | We are open to further discussion for this topic. |
| Huawei, HiSilicon | It seems to depend on the RAN4 reply on the UE condition. |
| ETRI | In our understanding, at least UL-DL switching should be avoided, and other conditions may up to the RAN4 reply. |
| LG | In single cell operation with two uplink carrier, the collision between a DMRS bundle and another uplink transmission occasion on other carrier can be occurred. Furthermore, within a carrier, collision between PUCCHs or between PUCCH and PUSCH may happen. Further study is needed. |

## DMRS optimization with bundling across PUCCH repetitions

DMRS location and granularity optimization is mentioned in a few companies’ contributions [[R1-2100098](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104-e/Docs/R1-2100098.zip), [R1-2100400](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104-e/Docs/R1-2100400.zip), [R1-2101021](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104-e/Docs/R1-2101021.zip)]. Furthermore, [[R1-2101713](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104-e/Docs/R1-2101713.zip)] has a proposal to clarify what is the scope of “DMRS bundling”, which is related to this topic. More specifically, [[R1-2101713](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104-e/Docs/R1-2101713.zip)] want to clarify whether b) in following figure is allowed by “DMRS bundling” for PUCCH repetitions?



Based on the input from these contributions, there are two types of DMRS location/granularity optimization.

* Type 1: on top of Rel-15/16 DMRS patten/location/granularity defined for PUCCH transmit in a slot, introduce new DMRS pattern/location/granularity for PUCCH transmit in a slot.
* Type 2: no change of Rel-15/16 DMRS patten/location/granularity defined for PUCCH transmit in a slot. Allow a PUCCH to be transmitted without DMRS in one or more slot(s) within a set of bundled slots.

To address this open issue on DMRS optimization, there are four alternatives:

* Alt 1: Neither type 1 nor type 2 DMRS optimization is supported.
* Alt 2: Only type 1 DMRS optimization is supported, type 2 DMRS optimization is not supported.
* Alt 3: Only type 2 DMRS optimization is supported, type 1 DMRS optimization is not supported.
* Alt 4: Both type 1 and level 2 DMRS optimization are supported.

Companies are encouraged to provide feedback on this open issue in the following table.

|  |  |
| --- | --- |
| **Company name** | **Comments on which alternative should be adopted** |
| Samsung | Alt 1: No need to design additional DMRS patterns.  Can be revisited/reevaluated after progress on DMRS bundling. |
| CATT | From our point of view, DMRS optimization is valuable to PUCCH as well. Type 1 has more flexibility and possibility to achieve a high-end optimization. We slightly support type 1. This issue is related to the definition of DMRS bundling duration. If DMRS bundling duration is signaled, the new DMRS pattern/location/granularity for PUCCH should be defined in the DMRS bundling duration, instead of in a slot.  In short, our first preference is Alt2 and second is Alt.4. |
| Xiaomi | Similar mechanism of PUSCH joint channel estimation can be considered. |
| ZTE | Alt 3.  Current DMRS configure within one slot is flexible enough. Type 1 DMRS optimization is not needed. For type 2 DMRS optimization, it expects some gain can be obtained as we evaluated for DMRS bundling across PUSCH repetition. |
| Panasonic | It can be discussed after progress on joint channel estimation in agenda item 8.8.1.3. |
| Intel | We think DMRS optimization for PUCCH is out of scope for DMRS bundling for PUCCH enhancements. |
| vivo | DMRS bundling for PUCCH with DMRS pattern/location/granularity optimization is not evaluated in SI phase. We should focus on the enhancements we have already justified through evaluation in the SI phase. |
| OPPO | Alt 4 or Alt2, the performance gain is expected. |
| Lenovo, Motorola Mobility | We are okay to consider Alt 4 with optimization for both type 1 and type 2. Also, similar mechanism should be considered for PUSCH joint channel estimation |
| Ericsson | Tend toward Alt 1, but can further discuss. Any DMRS optimizations should be well justified by performance gains in use cases of interest. |
| Qualcomm | Support Alt 1. We don’t think any DMRS optimizations are necessary or useful. |
| Nokia/NSB | We are open for discussion in this aspect depending on the progress of the AI. |
| NTT DOCOMO | We prefer to discuss both Type1 and Type2 to see whether we will see the gains or not, and also we may follow the discussion in 8.8.1.3. |
| Sharp | If coverage performance is improved by coding gain of Type 2, it can be discussed further. |
| Apple | Alt1. Based on evaluation results from multiple sources, DMRS optimization is not justified |
| InterDigital | We agree with Panasonic that this discussion depends on the progress in 8.8.1.3. We are open to discussion of benefits for Type 1 and Type 2. |
| CMCC | Though we expect more improvement through optimization of DMRS, the update of DMRS pattern of PUCCH should be cautious. The backward compatibility should be maintained. Alt 3 is slightly preferred. |
| Huawei, HiSilicon | The outcome from AI 8.8.1.3 can be reused, or have a joint discussion. |
| ETRI | We do not see strong need to further optimize, which is Alt 1. |
| LG | Support Alt 1. Since the existing DMRS of PUCCH is almost evenly located and granularity can be configured by additional DMRS. The optimization of DMRS is low priority. |

# Others

There are a few other proposals mentioned in submitted contributions to this agenda. FL’s initial assessment is that they are out of the scope of this agenda. They are listed below for now just for information purpose.

[[R1-2101129](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104-e/Docs/R1-2101129.zip)]: Before RRC connection is established, dynamic repetition factor for PUCCH can be indicated in SIB1.

[[R1-2101224](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104-e/Docs/R1-2101224.zip)]: The maximum number of repetitions for transmission of PUCCH repetition is 32.

[[R1-2101523](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104-e/Docs/R1-2101523.zip)]: The dynamic PUCCH repetition mechanism should be applied to all PUCCH formats and all UCI types including A-CSI.

# References

|  |  |  |
| --- | --- | --- |
| **Tdoc #** | **Title** | **Source** |
| [**R1-2100098**](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104-e/Docs/R1-2100098.zip) | Discussion on coverage enhancements for PUCCH | ZTE |
| [**R1-2100175**](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104-e/Docs/R1-2100175.zip) | PUCCH enhancements for coverage | OPPO |
| [**R1-2100198**](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104-e/Docs/R1-2100198.zip) | PUCCH coverage enhancement | Huawei, HiSilicon |
| [**R1-2100400**](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104-e/Docs/R1-2100400.zip) | Discussion on PUCCH enhancements | CATT |
| [**R1-2100460**](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104-e/Docs/R1-2100460.zip) | Discussion on PUCCH enhancements | vivo |
| [**R1-2100668**](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104-e/Docs/R1-2100668.zip) | Discussion on PUCCH enhancements | Intel Corporation |
| [**R1-2100715**](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104-e/Docs/R1-2100715.zip) | Discussions on coverage enhancement for PUCCH | LG Electronics |
| [**R1-2100747**](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104-e/Docs/R1-2100747.zip) | Discussions on PUCCH enhancements | InterDigital, Inc. |
| [**R1-2100798**](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104-e/Docs/R1-2100798.zip) | Considerations on PUCCH coverage enhancement | Spreadtrum Communications |
| [**R1-2100918**](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104-e/Docs/R1-2100918.zip) | Discussion on PUCCH enhancements | China Telecom |
| [**R1-2101021**](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104-e/Docs/R1-2101021.zip) | Discussion on PUCCH enhancement for NR coverage enhancement | Panasonic Corporation |
| [**R1-2101058**](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104-e/Docs/R1-2101058.zip) | Discussion on PUCCH enhancements | CMCC |
| [**R1-2101081**](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104-e/Docs/R1-2101081.zip) | PUCCH enhancements | ETRI |
| [**R1-2101129**](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104-e/Docs/R1-2101129.zip) | PUCCH enhancement | Xiaomi |
| [**R1-2101224**](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104-e/Docs/R1-2101224.zip) | PUCCH enhancements | Samsung |
| [**R1-2101398**](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104-e/Docs/R1-2101398.zip) | PUCCH coverage enhancement | Apple |
| [**R1-2101480**](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104-e/Docs/R1-2101480.zip) | PUCCH coverage enhancements | Qualcomm Incorporated |
| [**R1-2101523**](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104-e/Docs/R1-2101523.zip) | PUCCH Dynamic Repetition and DMRS Bundling | Ericsson |
| [**R1-2101548**](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104-e/Docs/R1-2101548.zip) | Dynamic PUCCH repetition factor indication | Sharp |
| [**R1-2101576**](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104-e/Docs/R1-2101576.zip) | Enhancements for PUCCH repetition | Lenovo, Motorola Mobility |
| [**R1-2101626**](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104-e/Docs/R1-2101626.zip) | PUCCH enhancements for coverage enhancements | NTT DOCOMO, INC. |
| [**R1-2101682**](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104-e/Docs/R1-2101682.zip) | Discussion on PUCCH enhancements for coverage enhancement | WILUS Inc. |
| [**R1-2101713**](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_104-e/Docs/R1-2101713.zip) | PUCCH coverage enhancements | Nokia, Nokia Shanghai Bell |