**3GPP TSG-RAN WG1 Meeting #104-e R1-210xxxx**

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

**Agenda item:** 8.1.2.1

**Source:** Moderator (Qualcomm)

**Title:** Discussion Summary for mTRP PDCCH Reliability Enhancements

**Document for:** Discussion/Decision

# **Introduction**

The Rel-17 WID for further enhancements on MIMO (FeMIMO) includes the following objective:

1. Enhancement on the support for multi-TRP deployment, targeting both FR1 and FR2:
	1. Identify and specify features to improve reliability and robustness for channels other than PDSCH (that is, PDCCH, PUSCH, and PUCCH) using multi-TRP and/or multi-panel, with Rel.16 reliability features as the baseline

This document focuses on PDCCH reliability part. The company proposals are summarized, and offline proposals drafted passed on company contributions.

# **Summary of Contributions and Offline Proposals**

## **Working Assumption on Alt3**

In the previous meeting, we had a working assumption to use Alt3 (two SS sets associated with corresponding CORESETs) for PDCCH repetition (Option 2 + Case 1). Based on the contributions in this meeting, a clear majority of companies support to confirm the working assumption. One company (FUTUREWEI) proposed to also increase the number of CORESETs. The technical benefits / drawbacks for each of the alternatives have been discussed extensively and are well-known among the group. Below are the views based on RAN1 #104-e contributions:

* Confirm WA (Alt3): FUTUREWEI, InterDigital, Huawei/HiSilicon, Lenovo/Motorola Mobility, ZTE, Fraunhofer, MediaTek, Intel, NEC, Nokia/NSB, CMCC, Qualcomm, DOCOMO, Ericsson
* Other Alts: CATT (Alt1-2), vivo (Alt1-2)
* In addition to Alt3: Huawei/HiSilicon (Alt1-3), CMCC (Alt1-3)

***FL Proposal 1: Confirm the working assumption: For PDCCH reliability enhancements with non-SFN schemes and Option 2 + Case 1, support Alt3 (two SS sets associated with corresponding CORESETs).***

Please comment if you object/disagree with confirming the WA:

|  |  |
| --- | --- |
| Company | Comments |
| NTT Docomo | Support the proposal. |
| InterDigital | We support FL’s proposal.  |
| Futurewei | Support. |

## **Intra-slot versus Inter-Slot**

Multiple companies discussed the pros/cons of inter-slot PDCCH repetition versus intra-slot PDCCH repetition. At the same time, all companies support at least intra-slot PDCCH repetition. Based on the contributions, multiple reasons have been mentioned from both sides: On the one hand, inter-slot PDCCH repetition requires higher latency just for conveying the control information, higher UE complexity, and additional specification work such as BD limit, overbooking, linking monitoring occasions, etc. On the other hand, reducing PDCCH blocking in congested scenarios and more flexibility in scheduling have been mentioned as the benefit of inter-slot PDCCH repetitions. Views based on the contributions are summarized below:

* Intra-slot only or with higher priority: vivo, Fraunhofer (higher priority), Spreadtrum (higher priority), Apple, Qualcomm, DOCOMO (higher priority), Ericsson (higher priority)
* Both intra-slot and inter-slot: OPPO, ZTE, Lenovo/Motorola Mobility, MediaTek, Intel, Nokia/NSB, Xiaomi, Samsung

Given the amount of work, and the fact that all companies support at least intra-slot while there are some concerns on supporting both, the following proposal is suggested to make progress.

***FL Proposal 2: At least support intra-slot PDCCH repetition.***

* ***FFS: Whether inter-slot PDCCH repetition is supported additionally.***

Please comment if the above is not acceptable to you:

|  |  |
| --- | --- |
| Company | Comments |
| NTT Docomo | Support the proposal. |
| InterDigital | We support FL’s proposal.  |
| Futurewei | Support |

## **Linking between SS sets / MO / PDCCH candidates**

**2.3.1. SS set / MO linking and SS set configuration restrictions**

For PDCCH repetition with Alt3, the UE needs to be aware of the two SS sets that are linked / paired. How to indicate the linking to the UE was discussed by multiple companies and options such as using RRC signalling or MAC-CE were proposed. In additions, SS set configuration restrictions have been proposed by majority of companies, such as restricting the two SS sets to have the same periodicity, same DCI formats to monitor, etc. Once the SS sets are linked, how to link monitoring occasions is also an additional issue addressed by multiple contributions. Also, three companies mentioned that CORESET configuration restrictions are needed additionally. More discussions are required for CORESET configuration restrictions as some other companies (e.g. DOCOMO, Intel) do not see the need. A summary of the inputs is provided below:

* SS set restrictions and linking: OPPO (same periodicity and symbol duration), Lenovo/Motorola, CATT, Fraunhofer, MediaTek, LG, Intel, Qualcomm, DOCOMO
	+ Two SS sets linked by MAC-CE: Fraunhofer, MediaTek
	+ Define SS set group (SSG) and SSs within a group are used for PDCCH repetition: Apple
* CORESET restrictions: Lenovo/Motorola, MediaTek, Apple
* MO linking: Huawei/HiSilicon, Lenovo/Motorola, LG, Intel (by configuration), Qualcomm
	+ LG: linked MO pairs are mutual exclusive

The restrictions required may also depend on intra-slot versus inter-slot. For example, for intra-slot, we need to ensure that both SS sets exist in the same slots, and hence, both periodicity and offset (RRC param *monitoringSlotPeriodicityAndOffset*) should be the same. However, for inter-slot PDCCH repetition, the offset may not need to be the same. Given that at least intra-slot case is supported by all companies (See Section 2.2), we can first focus on intra-slot PDCCH repetition. For linking MO’s, some companies pointed out that linked SS sets / MO’s should be mutually exclusive. Also, different options such as linking MO’s by configuration or by SS set restrictions (RRC param *monitoringSymbolsWithinSlot*) and some rules were discussed.

The following proposal is suggested based on the above:

***FL Proposal 3: For PDCCH repetition, support linking two SS sets by RRC configuration:***

* ***FFS: Whether MAC-CE can be used additionally***
* ***FFS: Whether a given SS set can be linked with more than one other SS set***
* ***The two linked SS sets have the same SS set type (USS/CSS) and the same DCI formats to monitor***
* ***At least for intra-slot PDCCH repetition, the two SS sets have the same periodicity and offset (monitoringSlotPeriodicityAndOffset), and the same duration***
	+ ***For linking monitoring occasions across the two SS sets that exist in the same slot:***
		- ***Alt1: Provide linking by configuration***
			* ***FFS: Whether a one-to-one mapping or mutual exclusive relationship between monitoring occasion pairs are required***
		- ***Alt2: The two SS sets have the same number of monitoring occasions within a slot and they are linked one-to-one***
	+ ***FFS: Conditions for inter-slot PDCCH repetition if supported***

Please provide your input:

|  |  |
| --- | --- |
| Company | Comments |
| NTT Docomo | We are fine with the proposal in general.For the second FFS bullet, we suggest to clarify that for a given SS set linked with more than one other SS Sets, linkages with different SS sets are used for repetition of different PDCCHs, since the maximum number of linked PDCCH candidates for repetition is two. |
| Ericsson | Support FL Proposal 3 if we set the “same duration” as FFS and also add “same number of MO in a slot” as FFS |
| InterDigital | We support FL’s proposal.  |
| Futurewei | Support |

**2.3.2. PDCCH candidate linking**

With respect to how to link two PDCCH candidates, multiple options have been proposed by companies as can be seen below:

* Same AL and same candidate index: OPPO, Huawei/HiSilicon (for Alt3), CATT, Fraunhofer, MediaTek, LG, Intel, Spreadtrum, Convida Wireless, Qualcomm, DOCOMO
* By configuration: FUTUREWEI, CATT, Intel (additionally), Nokia/NSB
* By wrap-around or truncation: Lenovo/Motorola

Given the majority support of linking candidates with same AL and the same candidate index, and the simplicity of it, the following proposal is suggested:

***FL Proposal 4: For PDCCH repetition, two PDCCH candidates in two SS sets are linked based on having the same AL and the same candidate index:***

* ***Two linked SS sets are configured with the same number of candidates for each AL.***

Please provide your input:

|  |  |
| --- | --- |
| Company | Comments |
| NTT Docomo | We support the main bullet.For the sub-bullet, we think whether two linked SS sets shall have same number of candidates can be further discussed. From our perspective, such restriction is not necessary. For a PDCCH candidate is not liked with another PDCCH candidate, it can be used for single transmission. |
| Ericsson | Support FL Proposal 4. We agree with DCM comment on non-linked candidates. i.e. FFS whether to support candidates that are not linked in order to support single TRP transmission, e.g. if CORESETs have different number of candidates |
| InterDigital | We support FL’s proposal. |
| Futurewei | We still think RRC configuration is the most versatile and most clear solution, but we can accept the proposal in principle. The proposed seems a bit restrictive, i.e., only one-to-one mapping is supported, and cannot support one-to-none mapping (i.e., the case described by DCM), one-to-multiple mapping, and so on. Maybe the same AL / same candidate index approach can be the baseline implicit approach, while the RRC configuration can be the explicit approach. |

## **Decoding Assumptions and Impact on BD / Overbooking**

**2.4.1. Number of BDs**

The following decoding Assumptions 1-4 have been identified in the previous meeting:

* Assumption 1: UE only decodes the combined candidate without decoding individual PDCCH candidates
* Assumption 2: UE decodes individual PDCCH candidates
* Assumption 3: UE decodes the first PDCCH candidate and the combined candidate
* Assumption 4: UE decodes each PDCCH candidate individually, and also decodes the combinedcandidate

Based on the contributions in RAN1 #104-e, the views are quite diverse in terms of which combination of decoding assumption should be assumed for further discussion:

* Assumption 3: InterDigital, OPPO,
* Assumptions 1, 2, 4: Huawei/HiSilicon
* Assumptions 1, 3, 4: NEC
* Assumption 1: ZTE, vivo, CMCC
* Assumptions 1 and 2: CATT
* Assumptions 1, 2, 3: Fraunhofer
* Assumptions 2, 3, 4: Intel
* Assumption 4: Fujitsu
* Assumption 2: Spreadtrum
* Assumptions 2 and 3: DOCOMO, Ericsson
* Assumptions 1 and 4: Xiaomi
* Assumptions 1 and 3: TCL communication
* Assumptions 1, 3, [4]: Futurewei (4 is needed only if dynamic network selection / overbooking occurs)

In terms of the performance, Huawei/HiSilicon and Qualcomm showed that Assumption 4 is more robust in certain scenarios while ZTE and Futurewei showed that difference is negligible.

In addition, multiple companies proposed that the number of BDs can be at least based on the UE capability reporting. Three types of capability have been proposed: 1) UE indicates the required number of BDs 2) UE indicates whether it supports soft-combining 3) UE directly indicates one or more decoding assumption out of decoding assumptions 1-4:

* Type-1: UE indicates required number of BDs: FUTUREWEI, OPPO, Fraunhofer, LG, Nokia/NSB, Samsung, Apple, Qualcomm
* Type-2: UE indicates whether it supports soft-combining: Fraunhofer, DOCOMO
* Type-3: UE indicates one or more of the decoding assumptions: Huawei/HiSilicon, Lenovo/Motorola

Considering the fact that for a UE supporting soft-combining, the number of BDs may also depend on UE implementation, Type-1 and Type-2 can be combined together. Furthermore, the network may benefit from additional flexibility if it knows whether UE performs soft-combining or not. Hence the following two options can be considered (note that since it is agreed that “the complexity associated with RE de-mapping / demodulation, 2 units are required”, for decoding assumption 1, the number of BDs should be larger than 1)

***FL Proposal 5: For number of BDs corresponding to two PDCCH candidates that are linked for PDCCH repetition, consider one of the following two options for UE capability***

* ***Option 1: UE reports whether it supports soft-combining or not***
	+ ***If soft-combining is supported, UE further reports one or more numbers as required number of BDs for the two PDCCH candidates***
		- ***Candidate values: 2, 3.***
			* ***FFS: Whether a value between 1 and 2 should be added to the candidate values***
* ***Option 2: UE reports one or more decoding assumptions out of decoding assumptions 1-4***
	+ ***Number of BDs for decoding assumptions 1:***
		- ***Alt1: 2BDs***
		- ***Alt2: A value between 1 and 2 BDs***
	+ ***Number of BDs for decoding assumptions 2 or 3: 2***
	+ ***Number of BDs for decoding assumption 4: 3***
* ***FFS: Network configuration based on the above UE capabilities***

Please provide your input:

|  |  |
| --- | --- |
| Company | Comments |
| NTT Docomo | We would like to clarify that for option1, if 2 BDs are assumed for both assumption1 and 3, when UE reports 2 BDs, does it mean UE supports both assumption1 and assumption3, or UE’s supporting of assumption1 or 3 is transparent to NW. In our view, whether UE supports assumption1 or assumption3 needs to be aware of by NW to make proper configuration. It is related to the discussion of inter-slot repetition and PDCCH overbooking. If inter-slot repetition is supported, in case of inter-slot repetition, assumption1 will lead to higher latency. And considering PDCCH overbooking, if one of the PDCCH candidate may be dropped, UE may not be able to decode the PDCCH since UE only decodes the combined candidate with assumption1.  |
| Ericsson | Don’t support the FL proposal. We don’t see the need for UE capability signaling for this feature. A basic PDCCH repetition functionality for all UEs that support such repetition is sufficient to support this feature, and there is no need to introduce and distinguish multiple levels of functionality within this feature by the introduction of UE capability signaling. Either the UE support PDCCH repetition or it does not. We propose that two BD is used, and whether UE implements soft combining or not is up to UE implementation (it is unlikely that RAN4 will introduce an additional PDCCH repetition test for soft combining).  |
| InterDigital | We support FL’s proposal. We think option 1 gives the flexibility to the NW to make the proper configuration to support either assumption while taking into account the UE’s capability.  |
| Futurewei | * Added our tdoc position in the summary before the FL proposal.
* We also think whether the UE performs soft combining or not can be transparent to the network.
* There does not seem to be sufficient discussion on dynamic network selection, in which the gNB may dynamically transmit only one PDCCH candidate. This may be due to the signal blockage at one TRP or PDCCH overbooking at one TRP (unless both candidates are dropped in this case). When this can happen, only Assumption 4 of 3 BDs can work. Otherwise, Assumption 1 of 1 BD and Assumption 3 of 2 BDs (moderately better than Assumption 1 in some cases with smart choice of the one individual candidate) are sufficient.
 |

**2.4.2. Overbooking**

Regarding the overbooking, the company proposals are diverse as shown below:

* InterDigital: Prioritize monitoring of repeated PDCCH candidates
* ZTE: Drop one of them instead of dropping both
* Intel: SS set dropping due to linkage for Assumptions 3 and 4
* Samsung: Per candidate-level
* Apple: Per group of SS sets
* Qualcomm: When 3 BDs are counted, the third one is counted as part of one of the SS sets
* DOCOMO: PDCCH repetitions are allocated together

Given the diverse inputs, and the fact that the decision for overbooking is also a function of the outcome of FL Proposal 5 above, this issue can be discussed in more details later.

## **Resolving ambiguities**

**2.5.1. Implicit PUCCH resource determination**

Three alternatives were identified in the previous meeting for this issue:

* Alt 1: Ensure same start CCE index (based on linking options) and the same number of CCEs in the two CORESETs (based on CORESET configuration restriction)
* Alt 2: Starting CCE index and number of CCEs in the CORESET of one of the linked PDCCH candidates is applied
	+ FFS:  Which one of the linked PDCCH candidates is used.
* Alt 3: It is up to the UE to determine the PUCCH resource based on the starting CCE index and number of CCEs in the CORESET of any of the two linked PDCCH candidates

Companies views are summarized below:

* Alt1: vivo, MediaTek, Apple
* Alt2: OPPO, Huawei/HiSilicon, Lenovo/Motorola, Fraunhofer, LG, Intel, Fujitsu, Spreadtrum, NEC, Nokia/NSB, CMCC, Xiaomi, Samsung, Convida Wireless, Qualcomm, DOCOMO, Ericsson
	+ CORESET ID: Lenovo/Motorola, Fraunhofer, DOCOMO, Ericsson
	+ SS set ID: Intel (if they end in the same symbol), Qualcomm, Ericsson
	+ The one that ends later: Intel, Spreadtrum
* Alt3: CATT

There is majority view to support Alt2. It is pointed out by multiple companies that Alt1 requires unnecessary restrictions while Alt3 may require multiple PUCCH decoding at the gNB side. In terms of “FFS: Which one of the linked PDCCH candidates is used.”, companies have different views. It should be noted that SS set IDs are always different, but if we want to allow PDCCH repetition with single-TRP, CORESET IDs could be allowed to be the same (in other words, whether associated CORESETs shall be always different requires further discussions).

***FL Proposal 6: When DL DCI is transmitted via PDCCH repetition, for PUCCH resource determination for HARQ-Ack when the corresponding PUCCH resource set has a size larger than eight, starting CCE index and number of CCEs in the CORESET of one of the linked PDCCH candidates is applied***

* ***Option 1: The one with the lowest CORESET ID is applied***
* ***Option 2: The one with the lowest SS set ID is applied.***
* ***Option 3: The one that ends later is applied.***
	+ ***If they end in the same symbol, choose either Option 1 or option 2.***

Please indicate your preference out of the three options above:

|  |  |
| --- | --- |
| Company | Comments |
| NTT Docomo | We are fine with either option1 or option2.  |
| Ericsson | Support Option 1 or 2.  |
| InterDigital | We support either option 1 or 2.  |
| Futurewei | Support. Based on the FL summary, it seems Option 2 is the simplest solution. |

**2.5.2. Rate matching**

The following companies mentioned that clarification may be needed in case both PDCCH repetitions overlap with the scheduled PDSCH in term of rate matching around both linked PDCCH candidates irrespective of which one is actually decoded: Lenovo/Motorola, vivo, Spreadtrum, Nokia/NSB, Qualcomm, DOCOMO, Ericsson.

Hence, the following proposal can be considered:

***FL Proposal 7: If a PDSCH is scheduled by a DCI in PDCCH candidates that are linked for repetition, and the resources of the PDCCH candidates overlap with the resources of the PDSCH, the PDSCH is rate matched around the union of two PDCCH candidates and the corresponding DMRS.***

Please provide your input:

|  |  |
| --- | --- |
| Company | Comments |
| NTT Docomo | Support the proposal. |
| Ericsson | Support Proposal 7 |
| InterDigital | We support FL’s proposal.  |
|  |  |
| Futurewei | Support |

**2.5.3. Issues related to timing**

Additional issues for which a rule may be needed to resolve the ambiguities related to timing aspects are proposed by multiple companies as below:

* Scheduling offset for default beam for PDSCH / CSI-RS scheduling: OPPO, Lenovo/Motorola, ZTE, vivo, MediaTek, LG, Intel, Spreadtrum, NEC, Nokia/NSB, CMCC, Qualcomm, DOCOMO, Ericsson, TCL communication
* Slot offset for scheduling the same PDSCH/PUSCH/CSI-RS/SRS: OPPO, Huawei/HiSilicon (first linked candidate), Lenovo/Motorola, ZTE, MediaTek, Intel, NEC, Nokia/NSB, CMCC
* Out-of-order: Lenovo/Motorola, MediaTek (restriction: no DCI in between PDCCH repetition), Intel, Nokia/NSB, CMCC, Qualcomm, DOCOMO, Ericsson
* Timelines (N2,Z): LG, NEC, Qualcomm

Majority of companies propose to use the later PDCCH candidate as reference to resolve the ambiguity for these cases:

***FL Proposal 8: At least for the following purposes, a reference PDCCH candidate is defined as the candidate that ends later in time among the two linked PDCCH candidates:***

* ***To determine the scheduling offset to identify whether a default beam should be used for PDSCH / CSI-RS reception.***
* ***To extend the definition of out-of-order / in-order for PDCCH-PDSCH and PDCCH-PUSCH: PDCCH ending symbol is the last symbol of the reference PDCCH candidate.***
* ***For PUSCH preparation time (N2) and CSI computation time (Z): Last symbol of the PDCCH is based on the last symbol of the reference PDCCH candidate.***
* ***If inter-slot PDCCH repetition is supported, for slot offset for scheduling the same PDSCH/PUSCH/CSI-RS/SRS: The slot of the reference PDCCH candidate is used as the reference slot.***

Please provide your input:

|  |  |
| --- | --- |
| Company | Comments |
| NTT Docomo | We support the proposal. |
| Ericsson | We support this proposal |
| InterDigital | We support FL’s proposal. |
| Futurewei | What if the reference candidate is not decoded by the UE? |

**2.5.4. Issues related to HARQ-Ack**

For DAI definition / Type-2 HARQ-Ack codebook construction, and when the two PDCCH candidates belong to different PDCCH monitoring occasions, a rule is needed to resolve the ambiguity. This is pointed out by the following companies: OPPO, Huawei/HiSilicon (first linked candidate), Lenovo/Motorola (first or last), ZTE, MediaTek, LG (first), Intel (ends earlier), Spreadtrum (first), NEC, Nokia/NSB, CMCC, Qualcomm (first), DOCOMO (first), Ericsson (first).

Most companies propose the earlier PDCCH monitoring occasion should be used as a reference in this case. This is because scheduling information for future monitoring occasions (e.g. in case of CA) may not be available at the time of transmitting the first PDCCH repetition. Hence, gNB may not know exactly how many other DCIs will be sent in the next PDCCH monitoring occasion, and as a result, the DAI value used for PDCCH repetition cannot be predicted if the later monitoring occasion is assumed as the reference.

Another issue that is somewhat related, is for determination of last DCI in order to identify PRI of which DCI should be used for PUCCH resource. This issue is pointed out by Huawei/HiSilicon.

***FL Proposal 9: If two PDCCH candidates that are linked for repetition do not belong to the same PDCCH monitoring occasion, the earlier PDCCH monitoring occasion is used as the reference for the following:***

* ***Definition of counter DAI / total DAI and Type-2 HARQ-Ack codebook construction.***
* ***Determining the last DCI for PUCCH resource determination based on the PRI field of the last DCI.***

Please provide your input:

|  |  |
| --- | --- |
| Company | Comments |
| NTT Docomo | Support the proposal. |
| Ericsson | Supports |
| InterDigital | We support FL’s proposal. |
| Futurewei | What if the earlier candidate that is supposed to be the reference is not decoded by the UE? |

**2.5.5. Other issues**

The following issues have also been identified based on the RAN1 #104-e contributions, which may require further discussions / more supporting companies:

* **Additional issue 1**: Starting symbol for PDSCH mapping type B as well as reference symbol for SLIV: Huawei/HiSilicon (first linked candidate), Qualcomm (last linked candidate)
* **Additional issue 2**: PDSCH beam when TCI field not present in DCI (when scheduling offset is equal to or larger than *timeDurationForQCL*): LG, Qualcomm
* **Additional issue 3**: PDCCH repetitions are associated with different CORESETPoolIndex values, and the need to use one of them as reference for PDSCH scrambling / CRS rate matching / HARQ-Ack / etc.: ZTE

Please comment regarding the additional issues above, and feel free to add other similar issues (related to resolving ambiguities), if any, in the list above:

|  |  |
| --- | --- |
| Company | Comments |
| NTT Docomo | We agree that the above issues need to be solved. |
| Ericsson | We support the FL initiative to capture a list of other issues to guide the preparation and discussion at the next meeting. |
| InterDigital | We agree that the additional issues should be discussed.  |
| Futurewei | Support |

## **Others**

Option 2 + Case 1 is agreed for PDCCH reliability enhancements. There are still some proposals to additionally support other options:

* Option 3: Lenovo/Motorola, CATT, vivo,
* Option 1: CATT

Given the discussions in the previous meeting and the amount of work needed for the details of Option 2 + Case 1, it is suggested to focus on the above proposals first. Other options can be discussed further if a need is identified by majority of companies.

# **Detailed Proposals / Observations**

|  |  |
| --- | --- |
| FUTUREWEI | Confirm the Working Assumption to support Alt3 (Two SS sets associated with corresponding CORESETs), and increase the number of CORESETs to up to 5Support a limited set of RRC configured linkages between the PDCCH candidates.Specify the lower bound as 1 BD per DCI and the upper bound as* + 2 BDs per DCI if dynamic network selection is not enabled; and
	+ 3 BDs per DCI otherwise.
 |
| InterDigital, Inc. | * Support at least Alt. 3
* Modify search rule to prioritize monitoring of repeated PDCCH candidates in a SS without increasing UE complexity

Support Assumption 3 for PDCCH decoding |
| OPPO | * Support association between two SS sets for PDCCH reliability enhancements with restrictions such as same period and same symbol duration
* Support to use linking same PDCCH candidate index within same aggregation level in each Search Space used for PDCCH repetition.
* Support assumption 3, i.e., decoding one individual and one combined PDCCH candidate at UE.
* Consider to report a value used to scale the BDs by UE which indicates the decoding assumption.
* Support Alt2, starting CCE index and number of CCEs in the CORESET of one of the linked PDCCH is applied to solve following issues:
	+ Implicit PUCCH resource determination
	+ DAI value
	+ Slot offset for scheduling the same PDSCH/PUSCH/CSI-RS/SRS
	+ Slot offset for default QCL assumption of PDSCH
 |
| Huawei, HiSilicon | Confirm the working assumption, i.e., support Alt 3 for PDCCH reliability enhancements for non-SFN schemesFor the case without available CORESETs to be configured for repetition, Alt 1-3 should be supportedThe following information is needed for the UE to determine the linked PDCCH candidates:* + Monitoring occasions for the linked PDCCH candidates;
	+ ID of the linked PDCCH candidates

The exact linkage between PDCCH candidates in linked monitoring occasions is predefined:* + For Alt 3, PDCCH candidates with the same AL and the same ID are linked;
	+ For Alt 1-3, PDCCH candidates with the same AL and different ID are linked

Assumptions 1, 3, and 4 have the same performance in the case without blockage, while in the case with blockage assumption 4 has the best performanceAt least assumption 1 should be supported, and assumptions 2, 4 can also be consideredThe decoding assumptions are UE capabilities, * + If UE is capable with Assumption-4, other decoding assumptions (e.g., Assumption 1 and 2) are also assumed to be supported by the UE

For decoding Assumption 2 and 4, gNB can transmit different DCIs on the linked PDCCH candidatesFor TDM based PDCCH repetition scheme, the monitoring occasion of the first linked PDCCH candidate is used for generating Type II HARQ-ACK codebookFor TDM based PDCCH repetition scheme, the monitoring occasion of the first linked PDCCH candidate is used for determining the last DCIFor TDM based PDCCH repetition scheme, the monitoring occasion of the first linked PDCCH candidate is used for determining the reference symbol/slot for SLIV indicationAlt 2 is supported for PUCCH resource determination for HARQ-ACK when the corresponding PUCCH resource set has more than eight PUCCH resources |
| Lenovo, Motorola Mobility | * Confirm the work assumption with supporting Alt.3 for PDCCH reliability enhancements with non-SFN schemes and Option 2 + Case 1.

Support both intra-slot and inter-slot repetition schemes for PDCCH enhancementMake restriction on CORESET parameter configuration, e.g. duration, frequencyDomainResources and on search space set parameter configuration, e.g. candidate number, monitoringSlotPeriodicityAndOffset, duration and monitoringSymbolsWithinSlot for facilitating soft combiningFurther study general mapping schemes to determine combined candidates for supporting flexible parameter configuration for linked CORESETs and search space setsSupport 4 kinds of decoding behaviour assumptions and use separate counting schemes for TDM/FDM based PDCCH transmission scheme corresponding to 4 kinds of decoding behaviour assumptions, respectively.Align the PDCCH candidate counting scheme between gNB and UE for determining blind decoding complexitySupport Alt 2. And a PUCCH resource for HARQ-ACK could be determined by the number of CCEs and the index of first CCE of PDCCH reception on the CORESET with a lowest ControlResourceSetIdIf the two determined PUCCH resources are non-overlapped in time domain, a UE could transmit a same HARQ-ACK information on both PUCCH resources for higher reliability in blockage scenarioUse reference PDCCH, e.g. the first or last PDCCH, to determine DAI value or location of ACK/NACK bit(s) in HARQ-ACK codebookClarify separate or joint DAI counting and HACK/NACK bit concatenation for PDCCH with normal transmission and PDCCH with repeat transmissionMake PDSCH rate matching on linked resources for PDCCH repeat transmission based on linkage between CORESETs, search space sets or candidatesThe transmission time of last PDCCH is used to determine QCL applying time for timeDurationForQCL and the slot offset for scheduled PDSCH/PUSCH/CSI-RS/SRSClarify whether out of order behaviour can be relaxed for PDSCHs/PUSCHs scheduled by enhanced PDCCHs with time domain overlappingClarify PDCCH ending symbol for determining order of order behaviour in case of PDSCH scheduled by PDCCH with repeat transmissionSupport Option 3, i.e. separate DCIs that schedule the same PDSCH/PUSCH/RS/TB/etc or result in the same outcomeFor Option 3, each DCI is transmitted independently as a R15 PDCCH candidate in valid CORESET with the corresponding TCIUse sequence number to identify the DCIs serving the same purposeIf multiple DCIs serving the same purpose can be sent out at different time, introduce in each DCI a timing offset to the time the last DCI is sent to avoid timing ambiguity |
| ZTE | * Confirm the working assumption, i.e. option 2+case 1+alt 3
* Assumption 1 has the lowest complexity, while assumption 4 has the largest complexity at UE side
* If two linked PDCCH candidates are in different slot or span, the BD counter of the later PDCCH candidate is larger than or equal to the BD counter of the former PDCCH candidate
* If two linked PDCCH candidates are in the same slot, the BD counter of the PDCCH candidate with a smaller SS set index equals to the BD counter of the PDCCH candidate pair
* Assumption 1, 3 and 4 show the similar performance, which are better than assumption 2
* Assumption 1 is supported
* In a certain slot or span, if the BD on the paired PDCCH candidates causes overbooking, UE can drop one of the paired SSs instead of dropping both the paired SSs
* One of two linked DCIs can be the reference to determine the scheduling information including default beam of PDSCH, CRS rate matching, scrambling ID, ACK/NACK feedback and scheduling slot offset
* Support multi-chance PDCCH transmission without explicit linkage, i.e. Option 3 + Alt3 + Case 2
	+ Two DCIs from two SS associated with corresponding CORESETs can schedule the same PDSCH/PUSCH/RS/TB/etc. or result in the same outcome.
	+ Two DCIs can also trigger independent signalling as Rel-15/16
 |
| CATT | * TDM and FDM based multiplexing schemes can both be supported
* The following schemes can be supported for TDM and FDM based multiplexing,
	+ Intra-CORESET multiplexing
	+ Intra-slot inter-CORESET multiplexing
	+ Inter-slot multiplexing
* To solve slot offset issue for scheduling the same PDSCH/PUSCH/CSI-RS/SRS, the following alternatives can be considered,
	+ Alt.1: Support Option 3 (multi-chance) to ensure two DCIs schedule the same PDSCH/PUSCH/CSI-RS/SRS
	+ Alt.2 Introduce a predefined or reference DCI or timing of DCI reception
* For PUCCH resource determination when the corresponding PUCCH resource set has a size larger than eight, Alt.3 (i.e., up to the UE to determine the PUCCH resource) is preferred
* Dynamic switching between STRP and MTRP can be supported explicitly, i.e., a signaling is transmitted by gNB to inform UE before the switching
* The following combinations for non-SFN schemes can be supported,
	+ Alt. 1-1 + Option 1
	+ Alt. 1-2, 3 + Option 2/3
* The following linkages among multiple PDCCH candidates can be considered to reduce complexity of blind detection.
	+ Linkage 1: Indexes of linked PDCCH candidates or SS sets or CORESETs can be configured or predefined.
	+ Linkage 2: Time and frequency resources of one DCI can be indicated by other DCI.
	+ Linkage 3: Association of TCI states of multiple repetitions can be configured, predefined or indicated by one DCI.
* In Linkage 1, time or periodicity information of the linked PDCCH candidates or SS sets or CORESETs shall be pre-defined or configured
* Assumption 1 and Assumption 2 can be further considered for BD limit
 |
| vivo | * For non-SFN based PDCCH, only support TDM based PDCCH repetition
* Compared to Alt1-2 and Alt1-3, Alt3 has higher signaling overhead, consumes larger number of CORESETs
* Support intra-slot PDCCH repetition only with minimum spec impact
* Alt1-2 is simpler for configuration of linking indication about PDCCH repetition
* UE only decodes the combined candidate without decoding individual PDCCH candidates
* Option3 and implicit linkage should be supported in order to provide scheduling flexibility at gNB in MTRP operation
 |
| Fraunhofer IIS, Fraunhofer HHI | * The following observations are made from the PDCCH reliability enhancement simulation results for FR1:
	+ PDCCH repetition and SFN-based PDCCH transmission from two TRPs improves PDCCH reliability.
	+ In the case of PDCCH repetition or multi-chance PDCCH from two TRPs, the hierarchy in terms of performance is as follows: hybrid decoding > soft-combining > selection decoding
* The following observations can be made from the PDCCH reliability enhancement simulations for FR2
	+ Blockage results in error floors for all methods. Multi-TRP schemes can reduce the error floor over the single-TRP scheme.
	+ Soft-combining and hybrid decoding perform better than selective decoding at low and high SNRs
* Confirm the following working assumption:
	+ For PDCCH reliability enhancements with non-SFN schemes and Option 2 + Case 1, support Alt3 (two SS sets associated with corresponding CORESETs)
* The search spaces sets that contain the linked PDCCH candidates are explicitly signaled via RRC or MAC-CE. MAC-CE is preferred for dynamic or semi-persistent linkage of the PDCCH candidates
* The PDCCH candidates with the same PDCCH candidate index in a given aggregation level in the two search space sets are linked with each other
* Assumption 4 shall not be considered for the process of decoding a DCI transmitted on multiple PDCCH candidates.
* The number of blind decoding attempts that could be counted for each method is as follows: ρ∈{0,1}
	+ Assumption 1 – Soft-combining only: 1+ρ
	+ Assumption 2 – Selection decoding: 2
	+ Assumption 3 – Hybrid decoding (select one candidate and decode, and soft-combining): 2+ρ
* A UE capability for the number of blind decoding attempts while decoding DCI transmitted on multiple PDCCH candidates is introduced
* The UE’s capability regarding soft-combining needs to be known at the gNB if gNB selection, i.e., the transmission of the DCI in only one of the associated PDCCH candidates, is allowed or possible in Option 2 + Case 1.
* The search space sets containing the linked PDCCH candidates shall be of the same search space type and the DCI formats to be monitored in both the search space sets shall also be the same.
* Support intra-slot repetition of PDCCH.
	+ FFS: Specifying inter-slot repetition
 |
| MediaTek Inc. | * Confirm the following working assumption. For PDCCH reliability enhancements with non-SFN schemes and Option 2 + Case 1, support Alt3 (two SS sets associated with corresponding CORESETs).
* Use the second candidate as the reference point for scheduling offset for “timeDurationForQCL”, DAI determination for type-2 codebook, and slot offset for scheduling the same PDSCH/PUSCH/CSI-RS/SRS
* Define that the UE doesn’t expect any other PDCCH between the first and the second candidate of PDCCH repetition for multi-TRP
* Do not define new BD/CCE limit for multi-TRP PDCCH enhancement. Leave it to UE implementation.
* Both intra-slot and inter-slot TDM can be supported for different use cases
* Support Alt 1 to reduce the UE’s blind decoding complexity
* Associate two search space sets which are mapped onto two different CORESETs for PDCCH repetition.
	+ Use the same configurations such as duration, nrofCandidates, monitoringSymbolsWithinSlot for two associated search space sets and cce-REG-MappingType, duration, the number of RBs for two corresponding CORESETs
	+ Transmit the same payload of DCI using PDCCH candidates with the same index (m\_(〖A,n〗\_CI )= m\_(〖B,n〗\_CI )) and the same aggregation level L in two associated search space sets A and B
* Introduce new MAC CE to activate/deactivate the association of two search space sets for PDCCH repetition.
 |
| LG Electronics | * For PDCCH repetition, linkage between two MO of search space sets is defined and the linked MO pairs are mutual exclusive
* For each linked MO pair, two PDCCH candidates with the same aggregation level and the same PDCCH candidate index are used to repeat the same DCI
* For MTRP PDCCH repetition, UE reports its BD assumption for a PDCCH candidate pair as UE capability, and gNB indicates equal or lower complexity BD assumption than what UE reports.
* For TDM based PDCCH repetition, timing values such as timeDurationForQCL, beamSwitchTiming, Z, and N2 should be defined by DCI reception time in the latest MO of a linked MO pair.
* For TDM based PDCCH repetition, DAI should be counted based on the earliest MO of a linked MO pair
* Clarify UE behavior for PDSCH TCI determination if TCI field is not present in repeated DCI.
* For PUCCH resource determination for HARQ-Ack, apply starting CCE index and the number of CCEs in the CORESET of one of the linked PDCCH candidates.
 |
| Intel Corporation | * Confirm the working assumption of using Alt 3 for supporting Option 2 + Case 1. The linked SS sets SS set-1 and SS set-2 should be configured with the same SS type and at least on common DCI format for monitoring.
* A baseline scheme for linkage is a fixed rule stating candidate k of SS set-1 is “linked” to candidate k of SS set-2 which creates all possible candidate-pairs. Consider further limiting the number of linked candidates for soft-combining for each AL using additional gNB → UE signalling.
* In the use cases of scheduling offset for “timeDurationForQCL”, Out-of-order / in-order definition for PDCCH-to-PDSCH and PDCCH-to-PUSCH, Slot offset for scheduling the same PDSCH/PUSCH/CSI-RS/SRS, implicit PUCCH resource determination for >8 PUCCH resources in the resource set define a reference PDCCH as the one that ends later if they end in different symbols and if they end in the same symbol, the PDCCH that is associated with the lower SS set index (Alt-2). In the use case of DAI for Type-2 codebook define a reference PDCCH as the one that ends earlier if they end in different symbols and if they end in the same symbol, the PDCCH that is associated with the lower SS set index.
* Do not support Assumption 1 for BD. Assumptions 2, 3 and 4 can be supported with BD=2, 2 and 3 respectively
* Overbooking rules (based on current specification) at SS set level granularity can be applied to assumption 2 and extended to assumptions 3 and 4 with additional condition of SS set dropping due to linkage and can be a baseline. Further study candidate level dropping rules in order to obtain a finer granularity of dropping (particularly for span-based monitoring where the BD limits are smaller)
* Support inter-slot mTRP PDCCH repetition that allows joint scheduling of PDCCH across multiple slots at the gNB to reduce blocking probability.
* No additional restrictions are necessary regarding time frequency overlap of SS sets or CORESETs participating in PDCCH repetitions with the condition that soft-combining of a PDCCH candidate—pair is not expected when the corresponding CCEs are overlapped
* Consider gNB → UE signalling of slots and monitoring occasions where a UE may expect PDCCH repetition transmission
 |
| Fujitsu | * For the blind decoding of PDCCH with repetitions, at least a UE capability is needed to be defined to support Assumption 4, which is:
	+ UE decodes each PDCCH candidate individually, and also decodes the combined candidate
* For PUCCH resource determination for HARQ-ACK when the corresponding PUCCH resource set has a size larger than eight, Alt 2 is preferred:
	+ Starting CCE index and number of CCEs in the CORESET of one of the linked PDCCH candidates is applied.
 |
| Spreadtrum Communications | * For non-SFN based PDCCH repetition, intra-slot PDCCH repetition can be prioritized for study.
* For non-SFN based PDCCH enhancement, at least consider the following for linkage between two PDCCH candidates:
	+ support pre-defined rule for building linkage at AL and PDCCH candidate level respectively.
	+ support linkage for PDCCH candidates with specific index.
* For non-SFN based PDCCH repetition, consider using the second PDCCH candidate as a reference for determining scheduling offset.
* For non-SFN based PDCCH enhancement, consider PDCCH monitoring occasion corresponding to the first PDCCH candidate as a reference for DAI definition.
* For non-SFN based PDCCH enhancement, support PDSCH rate matching around both linked PDCCH candidates
* For non-SFN based PDCCH enhancement, at least Assumption 2 can be considered for further study.
* For non-SFN based PDCCH repetition, support Alt 2 for PUCCH resource determination
 |
| NEC | * For non-SFN based multi-TRP PDCCH, confirm the working assumption
* For PUCCH resource determination, support Alt 2
* At least for scheduling offset for “timeDurationForQCL”, DAI for Type-2 codebook, Slot offset for scheduling the same PDSCH/PUSCH/CSI-RS/SRS, timing for CSI computation time and PUSCH preparation time, a reference candidate from the two PDCCH candidates can be defined, and parameters in the reference candidate will be used
* For UE decoding assumption, at least the combined candidate should be decoded (either one from assumption 1, 3 or 4). And UE behavior should be clarified based on joint consideration with TRP-specific beam failure recovery in agenda item 8.1.2.3.
 |
| Nokia, Nokia Shanghai Bell | * Confirm the working assumption on supporting Option 2 + Case 1 + Alt3 (two SS sets associated with corresponding CORESETs) and support this scheme for both intra-slot and inter-slot scenarios.
* Higher layer configuration shall link PDCCH candidates of the two search space sets.
* The UE shall determine which set of PDCCH candidates represent the “first” PDCCH and which set of PDCCH candidates represent the “second” PDCCH of the linked PDCCH candidates
* For both inter-slot and intra-slot PDCCH repetition BD limits, BD count for PDCCH repetition shall be based on the UE capability reporting
* To determine out-of-order / in-order definition in PDCCH repetition, the “first” PDCCH shall be used. The “second” PDCCH does not impact on the existing definitions of the out-of-order/in-order definitions.
* DAI operation in PDCCH repetition, DAI counting may refer only the “first” PDCCH.
* For deriving time offset for “timeDurationForQCL” and scheduling PDSCH/PUSCH/CSI-RS/SRS in PDCCH repetition, use the “second” PDCCH.
* When the PDSCH symbols are overlapping with PDCCH, rate match PDSCH around “first” and/or “second” PDCCH depending on which one(s) are having overlapping symbols with PDSCH
* For PUCCH resource determination for HARQ-ACK when the corresponding PUCCH resource set has a size larger than eight, starting CCE index and number of CCEs in the CORESET of “first” PDCCH candidates is applied
 |
| CMCC | * Support both Alt 1-3 and Alt 3
* One of the linked PDCCH candidates could be applied as the reference PDCCH candidate when multiple PDCCH candidates are transmitted with repetition scheme
* Support Assumption 1(UE only decodes the combined candidate without decoding individual PDCCH candidates) for PDCCH reliability enhancements
 |
| Xiaomi | * To design one signaling for beam indication of two CORESETs for Multi-TRP PDCCH
* Assumption 1 is supported for Multi-TRP PDCCH transmission
* Support to differentiate single TRP PDCCH transmission and Multi-TRP PDCCH transmission dynamically
* For inter-slot Multi-TRP PDCCH transmission, Assumption 4 for decoding is much better
* Prefer Alt 2 to determine PUCCH resource by parameters of one CORESET or by parameters of each PUCCH resource determined by each CORESET
* Support both intra-slot and inter-slot Multi-TRP PDCCH transmission with two as the maximum repetition number
 |
| Samsung | * Support both Option 2 and Option 3 for multi-TRP PDCCH repetition. Careful consideration of UE implementation complexity for Option 2 (repetition) is needed, with proper definition of UE behavior
* Support modified counting rule and the maximum limit for the number of monitored PDCCH candidates and non-overlapped CCEs based on a manner of PDCCH enhancement: repetition, multi-chance
* Support modified overbooking rule enabling to select the subset of PDCCH candidates and CCEs in a common or UE-specific search space sets which include repeated PDCCH candidates
* Support TDM based PDCCH repetition as a starting point for Option 2
* For the new default beam behaviors, support both single TCI state and multiple TCI states configured for mTRP PDCCH scheme
* For inter-slot PDCCH repetition with Option2, support PDSCH scheduling only from the last slot with PDCCH repetition and for intra-slot PDCCH repetition with Option2, support PDSCH scheduling from the same slot
* For PDCCH repetition with Option2 + Alt3, support PUCCH resource determination based on one of the configuration CORESETs, where the CORESET is selected either by the gNB or the UE
 |
| Apple Inc. | * Support to divide the SSs into multiple SS groups (SSGs), where the SSs within a group are used for PDCCH repetitions
* Support intra-slot/intra-span PDCCH repetition, where the SSs within a group and within a slot/span are used for PDCCH repetitions
* For QCL-TypeD collision handling and overbooking, support to enhance the priority rule to be defined in SSG level
	+ The priority for each SSG is counted based on the SS with highest priority within the SSG
* Support to count the number of BD/CCE in SSG level
	+ The BD/CCE for each SSG should be counted as X\*N, where N is the number of BD/CCE counted per SS within a SSG and N is a scaling factor reported by UE
* For non-SFN scheme, for PUCCH resource determination for HARQ-Ack when the corresponding PUCCH resource set has a size larger than eight, Alt1 should be supported, where gNB should ensure same start CCE index and the same number of CCEs in the two CORESETs.
 |
| Convida Wireless | * Two search space sets can be linked by configuration, where the search space sets can be associated with different CORESETs and TRPs
* The number of DCI repetitions across the two linked search space sets within K consecutive slots is configurable. Repetition within a monitoring occasion of a CORESET is not supported
* PDCCH can be repeated across candidates with the same PDCCH candidate index
* Support Alt 2: Starting CCE index and number of CCEs in the CORESET of one of the linked PDCCH candidates is applied
 |
| Qualcomm Incorporated | * Confirm the following working assumption
* Support intra-slot PDCCH repetition
* For PDCCH repetition, support
	+ Two SS sets are linked with each other based on higher-layer configuration.
	+ The two SS sets are expected to be configured with the same higher-layer parameters monitoringSlotPeriodicityAndOffse and duration.
	+ The two SS sets are expected to have the same number of monitoring occasions within a slot, i.e., the same number of 1’s in the two corresponding higher-layer parameter monitoringSymbolsWithinSlot.
		- The i’th monitoring occasion of the first SS set is linked with the i’th monitoring occasion of the second SS set.
* For PDCCH repetition, the two SS sets are expected to be configured with the same search space type, the same DCI formats to monitor, and the same number of candidates for each aggregation level.
	+ A PDCCH candidate in the first SS set is linked with a PDCCH candidate in the second SS set, if they have the same aggregation level and the same candidate index
* PDCCH repetition with decoding Assumption 4 (separate decoding as well as soft combining) is slightly more robust in scenario 1 (blockage) and significantly more robust in scenarios 2 and 3.
* UE can indicate through UE capability signalling whether it supports counting two PDCCH repetitions as two candidates or three candidates (or both) for PDCCH monitoring (toward the BD limit).
* When two PDCCH repetitions are counted as three candidates for monitoring, for overbooking in the PCell, the additional/third PDCCH candidate is counted as part of SS set with higher index among the two linked SS sets.
* In the case of PDCCH repetition, for PUCCH resource determination for HARQ-Ack when the corresponding PUCCH resource set has a size larger than eight, support Alt2.
	+ Use starting CCE index and number of CCEs in the CORESET of the PDCCH candidate that is associated with a SS set with a lower index
* If a PDSCH scheduled by a DCI in PDCCH candidates that are linked for repetition, and the resources of the PDCCH candidates overlap with the resources of the PDSCH, the PDSCH is rate matched around the resources of both PDCCH candidates
* When a PDSCH with mapping Type B is scheduled by a DCI in PDCCH candidates that are linked for repetition:
	+ The UE does not expect that the first symbol of the PDSCH to start earlier than the starting symbol of the PDCCH candidate with a later starting symbol.
	+ If UE is configured with ReferenceofSLIV-ForDCIFormat1\_2, and when receiving PDSCH scheduled by DCI format 1\_2 with CRC scrambled by C-RNTI, MCS-C-RNTI, CS-RNTI with K0=0, the starting symbol S is relative to the starting symbol S0 of the PDCCH candidate with a later starting symbol
* When a PDSCH / CSI-RS is scheduled by a DCI in PDCCH candidates that are linked for repetition, in order to determine the QCL assumption for PDSCH / CSI-RS, scheduling offset based on the later PDCCH candidate is considered
* In the case of PDCCH repetition:
	+ For defining out-of-order / in-order scheduling for PDCCH-PDSCH and for PDCCH-PUSCH, the ending symbol of PDCCH is the last symbol of the last PDCCH repetition.
	+ For PUSCH processing timeline (N2) and CSI computation timeline (Z), the last symbol of the PDCCH is the last symbol of the last PDCCH repetition
* If a PDSCH is scheduled by a DCI in PDCCH candidates that are linked for repetition, the TCI field is not present in the DCI, and the scheduling offset is equal to or larger than timeDurationForQCL, PDSCH QCL assumption is based on the CORESET with lower ID among the two CORESETs associated with the two PDCCH candidates
* For Type-2 HARQ-Ack codebook, the PDCCH monitoring occasion associated with a counter DAI / total DAI in a DCI detected in PDCCH candidates that are linked for repetition is the monitoring occasion of the earlier PDCCH candidate
 |
| NTT DOCOMO, INC | * Confirm the working assumption
* Support linkage between two PDCCH candidates via fixed rule based on same PDCCH candidate index
* Two SS sets for PDCCH repetition should be configured with the same periodicity
* Support assumption 2 and assumption 3 for PDCCH decoding.
	+ Both assumption 2 and assumption 3 require two units when counting toward BD limits.
* A default capability e.g. selective decoding can be defined for PDCCH repetition, and additionally UE can report whether soft combining is supported
* In case two PDCCH candidates are within a same slot/span, PDCCH overbooking procedure can be enhanced that two PDCCH candidates with linkage for PDCCH repetition are allocated together.
	+ Further study whether to support inter-slot/inter-span PDCCH repetition
* For PUCCH resource determination, starting CCE index and number of CCEs of one of the linked PDCCH candidates selected based on CORESET ID is applied
* Default beam is applied for PDSCH if offset between the reception of PDCCH candidate ending latest in time of the DL DCI and the corresponding PDSCH is less than the threshold timeDurationForQCL
* For out-of-order/in-order definition, the end of PDCCH is determined based on the PDCCH candidate ending latest in time.
* For Type-2 HARQ-ACK codebook, DAI indication is based on PDCCH candidate starting first in time and two PDCCH candidates for repetition are counted once in DAI
* Both linked PDCCH candidates for repetition should be rate matched for PDSCH
 |
| ASUSTeK | * Support linkage of PDCCH candidates by configuring search space set index in search space configuration
* For a paired of linked search space sets, RAN1 decides whether all PDCCH candidates in one search space set has respective repetition in the linked search space set
 |
| Ericsson | * Confirm the working assumption
* When PDCCH repetition is enabled for the UE, the default is that two PDCCH candidates are linked. FFS whether more than two can be configured to be linked
* Two blind decodes per PDCCH pair is counted towards BD limit for the UE when the PDCCH consists of two PDCCH candidates that are linked
* Support Alt.2 and use one of the linked PDCCH candidates in a CORESET having the lowest *controlResourceSetId*  or a SS set with lowest *searchSpaceId in the linked SS sets*
* The PDCCH symbol occurring latest in time in a pair of linked PDCCH candidates is defined as the last symbol regardless of which PDCCH candidate(s) the UE actually have detected
* The DAI counter DAI is incremented only at the first time a PDCCH is transmitted ( i.e., at the first PDCCH occasion) in a linked pair of PDCCH candidates
* The existing procedure for type 2 HARQ-ACK codebook construction is applied only for the first PDCCH occasion in case of PDCCH repetition regardless whether the PDCCH is actually detected in the first or/and the second PDCCH occasion
* In case the CORESET is not configured as unavailable for PDSCH and if a PDSCH scheduled by a pair of PDCCHs overlap with resources in the CORESETs containing the PDCCHs, PDSCH rate matching is done around the union of the linked PDCCH candidates and corresponding DM-RS
* DCI Format 2-2/2-3 are also supported by multi-TRP based PDCCH enhancements
* Consider finalizing PDCCH enhancement with intra-slot PDCCH repetition first
 |
| TCL communication | * For the reference for counting slot offset for PDSCH/PUSCH/CSI-RS/SRS, the first PDCCH candidate are preferred
* For BD counting assumption, assumption 1 and assumption 3 are preferred
* To enhance the overbooking rule, the explicit linkage between two PDCCH candidates can be exploited in the repetition based scheme
 |

# **Reference**

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[22] R1-2101415 Multi-TRP Enhancements for PDCCH, PUCCH and PUSCH, Convida Wireless

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[27] R1-2101662 Enhancements on Multi-TRP for PDCCH, PUCCH and PUSCH, TCL Communication Ltd.

# **Appendix: Previous Agreements**

**RAN1 #103-e:**

**Agreement**

For PDCCH reliability enhancements, support SFN scheme + Alt 1-1.

* FFS: TCI state activation for CORESET, impact on default beam, BFD resource for BFR

**Agreement**

For PDCCH reliability enhancements with non-SFN schemes, support at least Option 2 + Case 1.

* Maximum number of linked PDCCH candidates is two
* FFS: Details including how the two PDCCH candidates are counted toward the BD limits and impact on overbooking, if any
* Down-select at least one Alt from Alts 1-2 / 1-3 / 2 / 3
* FFS: Linking options such as a fixed rule based on the same PDCCH candidate index, based on start CCE, based on configuration, etc.
	+ FFS: additional restriction to facilitate soft combining
* FFS: implicit PUCCH resource determination for >8 PUCCH resources in the resource set, scheduling offset for “timeDurationForQCL”, Out-of-order / in-order definition for PDCCH-to-PDSCH and PDCCH-to-PUSCH, DAI for Type-2 codebook, Slot offset  for scheduling the same PDSCH/PUSCH/CSI-RS/SRS, rate matching PDSCH around the scheduling DCI.
* FFS: whether and how to support for DCI format 2\_x

**Working Assumption**

For PDCCH reliability enhancements with non-SFN schemes and Option 2 + Case 1, support Alt3 (two SS sets associated with corresponding CORESETs).

**Agreement**

For PDCCH reliability enhancements with non-SFN schemes and Option 2 + Case 1, CCEs of the two PDCCH candidates are counted separately following Rel. 15/16 procedures. Further study the BD limit by considering the following

* With respect to the complexity associated with RE de-mapping / demodulation, 2 units are required
* With respect to the complexity associated with decoding, the following assumptions can be further discussed:
	+ Assumption 1: UE only decodes the combined candidate without decoding individual PDCCH candidates
	+ Assumption 2: UE decodes individual PDCCH candidates
	+ Assumption 3: UE decodes the first PDCCH candidate and the combined candidate
	+ Assumption 4: UE decodes each PDCCH candidate individually, and also decodes the combinedcandidate
* Note 1: The Assumptions 1-4 are for discussion purpose only, and they may or may not have specification impact.
	+ FFS: The relationship between UE capability, RRC configuration, and the BD limit, and whether the Assumptions 1-4 are relevant for this purpose.
* Note 2: the BD /CCE limit here is counted based on the configuration of PDCCH monitoring capability (e.g. per slot or per span).

**Conclusion**

Group-common DCI formats (DCI formats 2\_x) are not precluded for multi-TRP PDCCH reliability enhancements and can be discussed with a lower priority compared to UE-specific DCI formats.

Note: Enhancements required for DCI formats 2\_x, if any, can be discussed case-by-case.

**Agreement**

When DL DCI is transmitted via PDCCH repetition (Option2 + Case 1), for PUCCH resource determination for HARQ-Ack when the corresponding PUCCH resource set has a size larger than eight:

* Alt 1: Ensure same start CCE index (based on linking options) and the same number of CCEs in the two CORESETs (based on CORESET configuration restriction)
* Alt 2: Starting CCE index and number of CCEs in the CORESET of one of the linked PDCCH candidates is applied
	+ FFS:  Which one of the linked PDCCH candidates is used.
* Alt 3: It is up to the UE to determine the PUCCH resource based on the starting CCE index and number of CCEs in the CORESET of any of the two linked PDCCH candidates
* Other alternatives are not precluded.

**RAN1 #102-e:**

**Agreement**

The following is agreed for evaluation of PDCCH

* According to the evaluation scenario (e.g., at FR1 in urban macro / at FR1 in indoor hotspot / at FR2 in indoor hotspot), one of three Tables (Table A.3-1 ~ A.3-3) of 38.824 can be a baseline of EVM for Rel-17 FeMIMO item 2a.
	+ System bandwidth other than those mentioned in the Tables can be considered and reported by the companies.
* In addition, the following table is used for EVM for Rel-17 FeMIMO item 2a (Common assumptions for PDCCH/PUCCH/PUSCH)

|  |  |
| --- | --- |
| **Parameters** | **Values** |
| The number of TRPs | 2 |
| Channel model | TDL for FR1 (CDL for FR1 can be optionally used)CDL for FR2 (TDL for FR2 can be optionally used) |
| Path-loss modeling | {0,3,6} dB gap between TRPs |
| Blockage | Blockage model from Rel-16 (x dB power offset with probability p): Companies to report x and p, and other assumptions, if any. |
| Target BLER | [10^-3, 10^-4, 10^-5]: BLER values shown in plots should be based on enough number of samples, e.g., ~100/BLER samples |

* The following table is used for detailed assumptions for PDCCH

|  |  |
| --- | --- |
| **Parameters** | **Values** |
| Baseline schemes | Option 1: Rel-15 PDCCHOption 2: Spec transparent SFNFor FR1: Both options 1 and 2 can be consideredFor FR2: Option 1. |
| AL | 8 as baseline. Companies are encouraged to simulate other AL’s additionally for different code rate regimes. |
| # of RBs/symbols | 1 or 2 symbols. Companies to report # of RBs.  |
| DCI payload | 40+24(CRC)=64 as baseline. Other payload values are not precluded.  |
| CCE-to-REG mapping | Both Interleaved and non-interleaved can be considered. Companies to report the assumptions including interleaverSize in the case of interleaved. |
| REG bundling size | 6 and 2 as baseline. |
| Precoding assumptions | Precoding cycling, precoder granularity=REG bundle as baseline.Closed-loop precoding can be used optionally |
| Schemes | Details of the schemes used (including TDM,FDM, etc.) to be reported by companies. |
| Receiver assumption  | Up to companies to report |

**Agreement**

To enable a PDCCH transmission with two TCI states, study pros and cons of the following alternatives:

* Alt 1: One CORESET with two active TCI states
* Alt 2: One SS set associated with two different CORESETs
* Alt 3: Two SS sets associated with corresponding CORESETs
* At least the following aspects can be considered: multiplexing schemes (TDM / FDM/ SFN / combined schemes), BD/CCE limits, overbooking, CCE-REG mapping, PDCCH candidate CCEs (i.e. hashing function), CORESET / SS set configurations, and other procedural impacts.

**Agreement**

For non-SFN based mTRP PDCCH reliability enhancements, study the following options:

* Option 1 (no repetition): One encoding / rate matching for a PDCCH with two TCI states
* Option 2 (repetition): Encoding / rate matching is based on one repetition, and the same coded bits are repeated for the other repetition. Each repetition has the same number of CCEs and coded bits, and corresponds to the same DCI payload.
	+ Study both intra-slot repetition and inter-slot repetition
* Option 3 (multi-chance): Separate DCIs that schedule the same PDSCH /PUSCH /RS/TB/etc. or result in the same outcome.
	+ Study both cases of DCIs in the same slot and DCIs in different slots

Note 1: Companies are encouraged to evaluate the different options based on agreed LLS assumptions for possible down-selection in RAN1#103-e.

Note 2: The actual encoding / rate matching chain for PDCCH polar coding (i.e. 38.212 Sections 5.3.1 / 5.4.1 / 7.3.3 / 7.3.4) is not changed in the options above.

**Agreement**

For mTRP PDCCH reliability enhancements, study the following multiplexing schemes

* TDM : Two sets of symbols of the transmitted PDCCH / two non-overlapping (in time) transmitted PDCCH repetitions / non-overlapping (in time) multi-chance transmitted PDCCH are associated with different TCI states
	+ Aspects and specification impacts related to intra-slot vs inter-slot to be discussed
* FDM : Two sets of REG bundles / CCEs of the transmitted PDCCH / two non-overlapping (in frequency) transmitted PDCCH repetitions / non-overlapping (in frequency) multi-chance transmitted PDCCH are associated with different TCI states
* SFN : PDCCH DMRS is associated with two TCI states in all REGs/CCEs of the PDCCH
	+ Note: There is dependency between this scheme and AI 2d (HST-SFN )
* Note: Combinations of the schemes are not precluded, and they can be discussed at a later stage.

**Agreement**

For Alt 1 (one CORESET with two active TCI states), study the following

* Alt 1-1: One PDCCH candidate (in a given SS set) is associated with both TCI states of the CORESET.
* Alt 1-2: Two sets of PDCCH candidates (in a given SS set) are associated with the two TCI states of the CORESET, respectively
* Alt 1-3: Two sets of PDCCH candidates are associated with two corresponding SS sets, where both SS sets are associated with the CORESET and each SS set is associated with only one TCI state of the CORESET
* Note 1: A set of PDCCH candidates contain a single or multiple PDCCH candidates, and a PDCCH candidate in a set corresponds to a repetition or chance
* Note 2: How one or more PDCCH candidates are counted for monitoring (for BD limit) is FFS
	+ The note is applicable also to other alternatives

**Agreement**

For Alt 1-2/1-3/2/3, study the following

* Case 1: Two (or more) PDCCH candidates are explicitly linked together (UE knows the linking before decoding)
	+ FFS: How the explicit linkage is derived/determined by the UE
* Case 2: Two (or more) PDCCH candidates are not explicitly linked together (UE does not know the linking before decoding)
	+ FFS: How the UE knows the linkage after decoding