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Title: Open issues and corrections for NR PDCCH
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1 Introduction

This contribution addresses leftover issues on DL control signaling for Rel-15 including PDCCH structure and search space. For each section we also discuss and provide corrections, where necessary, to the endorsed PHY specifications.

2 PDCCH Structure and search space monitoring

2.1 Relationship between SSB, CORESET #0 and Search Space #0

In order to achieve a common understanding on SSB/CORESET#0/SS#0, extensive discussions took place at the last two RAN1 meetings culminating in the following agreements and conclusion:

Agreements:

Update previous agreements as follows:

- NW and UE maintain the same understanding on SSB/CORESET#0/SS#0 in connected_mode **at least** for non-broadcast PDCCH **and for broadcast PDCCH**
 - Solutions FFS
- For the broadcast PDCCH, it is up to UE which common search space to monitor based on which SSB in both **connected**, in-active, and idle modes
- Unicast PDSCH can be scheduled by a DCI associated with the CORESET #0

Conclusion:

- No new RRC signaling for TCI-state configuration for the CORESET#0 is introduced.
- No new MAC-CE for TCI-state indication for the CORESET#0 is introduced.
- FFS: Whether the existing RRC configuration and/or existing MAC-CE field can be used to configure/indicate dedicated TCI-state or SSB index for the CORESET#0
- FFS: Whether/how to support BFR for the CORESET#0

The following alternatives were discussed in RAN1 but without conclusion:

Alt-1: Clarify that broadcast PDCCH uses selected SSB as QCL source for receiving broadcast data and that configured TCI states for CORESET #0 are used for reception of unicast data scheduled by PDCCH on search spaces other than SS#0

Alt-1': TCI state can be configured for CORESET #0 where the QCL reference is only an SSB. Once TCI state is configured for CORESET #0, the UE follows QCL assumption based on the TCI state configuration for both broadcast PDCCH and unicast PDCCH in the search space set(s) associated with the CORESET #0

Alt-2: CORESET #0 is not RRC configured with TCI states. According to the agreement above, the selected SSB is used as the QCL reference for reception of both broadcast and unicast PDCCH transmitted in CORESET #0. The selected SSB is indicated explicitly to the UE by MAC-CE signalling. The MAC-CE message contains the ID of the selected SSB. The selected SSB is the most recent one between MAC-CE and SSB selected as part of CBRA or CFRA.

Alt-3: Any search space associated with the CORESET #0 cannot be used for unicast PDCCH with QCL Type D after RRC connection is established.

Alt-3': Any search space associated with the CORESET #0 cannot be used for unicast PDCCH with QCL Type D after RRC connection is established. Align 6 PRB grid b/w CORESET #0 and other CORESETs. CORESET other than #0 can be configured for unicast PDCCH so that same physical resource configuration with the CORESET #0 with dedicated TCI-state configuration. In this case, no need to configure TCI state on CORESET #0 itself.

Alt-1 and Alt-1' introduce new RRC signaling for CORESET#0 which is against the spirit of the recent conclusion and should be abandoned.

Alt-3 simply prohibits the transmission of unicast PDCCH in CORESET#0 after RRC connection is established. It is against the spirit of the agreement above that unicast PDSCH can be scheduled by a DCI associated with the CORESET #0 because it places restriction on monitoring with QCL Type D linkage. Alt-3' introduces a configuration for another CORESET which has the same resource allocation as CORESET#0. Actually CORESET#0 is always known by a UE after the initial access procedure. If the network wants to configure a search space associated with CORESET#0, it can directly provide the ID #0 in the SearchSpace IE. Moreover, this solution introduces further specification effort to align the CORESET #0 grid with that of other configured CORESETs (this was previously discussed without any consensus to change).

Alt-2 does not introduce new RRC signaling or new MAC CE and is a straightforward way to go. For this alternative the TCI state indication for UE-specific PDCCH MAC CE is identified by a MAC PDU subheader with LCID. It has a fixed size of 16 bits with following fields: Serving Cell ID, BWP ID, CORESET ID, TCI State ID and reserved bits. Figure 1 shows the MAC CE structure described in [1]. Considering that the TCI-state pool is configured by the gNB, the MAC CE can indicate a TCI-state ID from the TCI-state pool to link to the SSB obtained in CFRA/CBRA. One concern is whether Alt-2 requires modifications to MAC specifications by defining a new MAC CE command. From Figure 1, the CORESET ID field is 4 bits, which supports the maximum of 12 configured CORESETs on a carrier as well as CORESET #0.

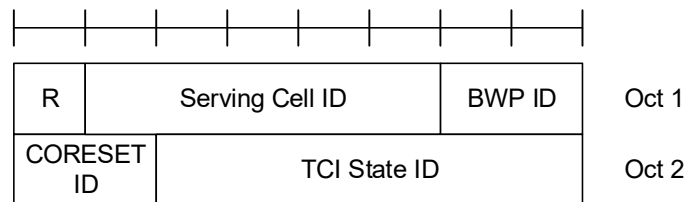


Figure 1 TCI State Indication for PDCCH MAC CE

Furthermore, if the UE selects the TCI state ID corresponding to SSB selected as part of a CBRA or CFRA or BM procedure, there is no issue and explicit MAC CE signaling is not needed. Consequently, it is straightforward to specify that the UE monitors search spaces in CORESET#0 with PDCCH DMRS quasi co-located with the SSB the UE identified during the more recent RA procedure in the initial BWP.

Proposal 1: Adopt Alt-2 for CORESET #0 QCL relationship with the following update:

- **CORESET #0 is not RRC configured with TCI states. For monitoring search spaces associated with CORESET #0, the UE assumes that the DM-RS antenna port associated with PDCCH reception is quasi co-located with the SS/PBCH block the UE identified during the most recent RA procedure or the TCI state ID for CORESET#0 is indicated by MAC CE.**

Regarding BFR support for CORESET #0, two periodic CSI-RS and/or SSB resource sets, i.e. \bar{q}_0 and \bar{q}_1 , could be configured by the gNB for a connected mode UE. Correspondingly, two thresholds are also configured for these two RS resource sets respectively. The physical layer in the UE assesses the radio link quality according to the set \bar{q}_0 of resource configurations against the threshold $Q_{out,LR}$. If the radio link quality for all corresponding resource configurations in the set \bar{q}_0 that the UE uses to assess the radio link quality is worse than the threshold $Q_{out,LR}$, the physical layer in the UE provides an indication to higher layers. Then, the UE could provide a preferred beam in terms of a CSI-RS index or SSB index included in set \bar{q}_1 whose corresponding L1-RSRP measurement is greater than or equal to the $Q_{in,LR}$ threshold through at least CFRA. During the BFR procedure, the UE monitors PDCCH in a BFR search space set and keeps monitoring in the other configured search space sets until receive an activation for a TCI state. As described in above, the beam failure recovery procedure is general to CORESETs and we believe it is also feasible for CORESET#0.

Observation: The current beam failure recovery procedure can also be applied to CORESET#0.

At the RAN1 #93 meeting, RAN1 clarified its understanding of a RAN2 agreement on how a UE acquires CORESET #0 and SS #0 [2][3]. RAN2 had further discussion on this issue at the RAN2 AH-1807 meeting, with the following agreement:

=> Change "controlResourceSetZero" second sentence to "Even though this field is only configured in the initial BWP (BWP#0) the UE operating in a different BWP acquires the CORESET#0 if the conditions defined in FFS_Spec, section FFS_Section are satisfied)." Similar change to be made to the similar text in searchSpaceZero.
=> Change to be added to the rapporteur EN-DC CR

The above agreement has been addressed in the latest version of 38.331.

We provide a TP for 38.213 Sec. 10.1 to capture the UE behavior according to the RAN1 agreement in #93.

Proposal 2: Adopt the following TP capturing UE acquisition of CORESET #0 and SS #0 to align with the description in 38.331.

If a UE is provided with the higher layer parameters *controlResourceSetZero* and *searchSpaceZero* in *PDCCH-ConfigCommon* the UE determines the corresponding control resource set and search space set according to the procedure described in Subclause 13. The UE monitors PDCCH candidates in a search space set associated with *controlResourceSetZero* only if the bandwidth determined for *controlResourceSetZero* in Subclause 13 is contained in the active DL BWP and the active DL BWP is configured with the same numerology as *controlResourceSetZero*.

2.2 Collision between CORESETs with different TCI states

The TCI state configured for a CORESET could indicate QCL-TypeA, or QCL-TypeA and QCL-TypeD. If only QCL-TypeA is configured for all the overlapped CORESETs, UE is still able to monitor PDCCH candidates in each CORESET according to the respective TCI state configured by RRC or indicated by a MAC CE. If QCL-TypeD is configured for one or more of the overlapping search spaces associated with different CORESETs, UE behavior should be defined because a UE may not be able to monitor search spaces on different beams simultaneously. One possible solution for this issue was discussed at the last meeting and shown below [4]:

- For a UE monitors multiple search spaces associated with different CORESETs,
 - if the monitoring occasions of the search spaces are overlapped in time [or are separated less than *Threshold-Sched-Offset* in time], the UE may assume that the DM-RS of PDCCH in the search spaces are quasi co-located with the RS(s) in the TCI state with respect to the QCL parameter(s) used for PDCCH quasi-co-location indication of the lowest CORESET-ID among the CORESETs associated with the search spaces.

However, this proposed mechanism actually reverts the previous agreement where the TCI state is configured via RRC signaling per CORESET. Following this agreement, UE monitoring is only meaningful on search spaces associated with a single CORESET if overlapping CORESETs have different QCL-TypeD properties. A simpler solution therefore, is that the UE monitors search spaces associated with a single CORESET. For example, the CORESET with lowest ID has higher priority. Whilst this is simple, we note that it is possible that two CORESETs overlap where a CSS is associated with the CORESET with higher ID while the one with a lower ID does not have an associated CSS. In this case, the CORESET with a CSS should be prioritized.

Proposal 3: If in a monitoring occasion a UE monitors multiple search spaces associated with different CORESETs with different QCL-TypeD properties:

- The UE monitors search spaces associated with a CORESET if at least one of the search spaces is a common search space.
- If two or more CORESETs have associated CSS, the UE monitors the CORESET with the lowest CORESET ID.

3 Miscellaneous corrections to 38.213 Section 10

3.1 Sec. 10.1

A RAN1 ad hoc #1801 agreement listed the RNTI(s) which are associated with CSS and USS respectively.

Agreements:

- For each search space configuration configured by UE-specific RRC signaling, the UE is informed whether the search space configuration is CSS or USS, together with the following information, as part of the search space configuration:
 - Which DCI format(s) to monitor
 - For a CSS,
 - DCI format 0_0 and DCI format 1_0
 - In which case, the UE monitors the DCI format with CRC scrambled by C-RNTI, CS-RNTI (if configured), SP-CSI-RNTI (if configured), RA-RNTI, TC-RNTI, P-RNTI, SI-RNTI
 - For USS,
 - A UE monitors the DCI format with CRC scrambled by C-RNTI, CS-RNTI (if configured), TC-RNTI (if a certain condition is met), and SP-CSI-RNTI (if configured)
 - Further discussion offline the association of the RNTIs with DCI formats
 - Monitoring of multiple DCI formats can be configured for one USS

We notice that the SP-CSI-RNTI is missing in the current version of 38.213 Sec. 10.1 and propose the following addition.

Proposal 4: Adopt the following TP capturing the missing SP-CSI-RNTI associated with a search space set.

10.1 UE procedure for determining physical downlink control channel assignment

<-----omitted----->

- a Type3-PDCCH common search space set configured by *SearchSpace* in *PDCCH-Config* with *searchSpaceType = common* for DCI formats with CRC scrambled by INT-RNTI, SFI-RNTI, TPC-PUSCH-RNTI, TPC-PUCCH-RNTI, or TPC-SRS-RNTI and, only for the primary cell, C-RNTI, MCS-C-RNTI, SP-CSI-RNTI, or CS-RNTI(s); and
- a UE-specific search space set configured by *SearchSpace* in *PDCCH-Config* with *searchSpaceType = ue-Specific* for DCI formats with CRC scrambled by C-RNTI, MCS-C-RNTI, SP-CSI-RNTI, or CS-RNTI(s).

<-----omitted end----->

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- if search space set *s* is a common search space set
- an indication by higher layer parameter *dci-Format0-0-AndFormat1-0* to monitor PDCCH candidates for DCI format 0_0 and DCI format 1_0 with CRC scrambled by a C-RNTI, an MCS-C-RNTI (if configured), a CS-RNTI (if configured), an SP-CSI-RNTI (if configured), RA-RNTI, TC-RNTI, P-RNTI, or a SI-RNTI

<-----omitted end----->

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If a UE is provided one or more search space sets by corresponding one or more higher layer parameters *searchSpaceZero*, *searchSpaceSIB1*, *searchSpaceOtherSystemInformation*, *pagingSearchSpace*, *ra-SearchSpace*, and the UE is provided with a C-RNTI, an MCS-C-RNTI, an SP-CSI-RNTI, or a CS-RNTI, the UE monitors PDCCH candidates for DCI format 0_0 and DCI format 1_0 with the C-RNTI, the MCS-C-RNTI, the SP-CSI-RNTI, or the CS-RNTI in the one or more search space sets.

<-----omitted end----->

4 Conclusion

This contribution described open issues and corrections to Rel-15 NR PDCCH. For brevity we summarize the proposals here but the reader is encouraged to take note of the TPs in the document.

- **Proposal 1: Adopt Alt-2 for CORESET #0 QCL relationship with the following update:**
 - CORESET #0 is not RRC configured with TCI states. For monitoring search spaces associated with CORESET #0, the UE assumes that the DM-RS antenna port associated with PDCCH reception is quasi co-located with the SS/PBCH block the UE identified during the most recent RA procedure or the TCI state ID for CORESET#0 is indicated by MAC CE.
- **Proposal 2: To adopt the above TP in order to capture the clarification on the understanding of RAN2's agreement on how a UE acquires CORESET#0 and SS#0.**
- **Proposal 3: For a UE monitors multiple search spaces associated with different CORESETs:**
 - If CORESETs overlap and only one of them has a CSS, the UE should monitor the one with the CSS.
 - If two or more CORESETs have a configured CSS, then it should drop the one with the lowest CORESET ID.
- **Proposal 4: Adopt the following TP capturing the missing SP-CSI-RNTI associated with a search space set.**

Besides, we have the following observation on BFR procedure for CORESET#0:

- **Observation: The current beam failure recovery procedure can also be applied to CORESET#0.**

5 References

- [1]. TS38.321 v15.3.0
- [2]. R1-1807838, “Offline sum Thr 7.1.3.1.2”, RAN1#93, NTT DOCOMO
- [3]. R2-1812411, “Introduction of SA”, RAN2#103, Ericsson
- [4]. R1-1809855, “Summary AI 7.1.3.1_r7”, RAN1#94, NTT DOCOMO