

Source: vivo
Title: Remaining issues on physical downlink control channel
Agenda Item: 7.1.3.1
Document for: Discussion and Decision

1. Introduction

In this contribution, we discuss some remaining issues on physical downlink control channel (PDCCH).

2. PDCCH monitoring for beam failure recovery

The BFR search space set and the associated CORESET are configured and only activated for beam failure recovery procedure. A UE is not expected to monitor the BSR-SS before BFR procedure (e.g., PRACH transmission). After the UE sending PRACH for contention-free BFR, it has been agreed in the previous meeting [1] that all configured search spaces before dedicated BFR PRACH transmission for BFR are monitored.

Agreement

Concerning the questions in RAN2 LS (R1-1808166) on BFR

Question 1: After UE sending PRACH for contention-free BFR, does the UE continue monitoring PDCCH candidates in configured search spaces monitored before PRACH, in addition to the search space indicated by recoverySearchSpaceId?

- RAN1 response: Yes, all configured search spaces before dedicated BFR PRACH transmission for BFR are monitored

With this agreement, the number of monitored PDCCH search space sets may dynamically vary during BFR procedure. Consequently, the PDCCH BD/CCE counting and search space set mapping should be properly handled considering the activation and deactivation of BFR-SS.

The most simple and straightforward solution is that, the PDCCH BD/CCE counting and search space set mapping rule always check the BFR-SS, no matter whether it is activated or not. This is also aligned with another agreement that the PDCCH BD/CCE counting is only based on the *configured* PDCCH decoding candidates.

Agreements:

- PDCCH BD/CCE counting is only based on the configured PDCCH decoding candidates (i.e., irrespective of whether or not a PDCCH decoding candidate is dropped, e.g., due to collision with other channels/signals)
 - Check further offline on potential spec impact

However, BFR should be considered as an exception case rather than a regular operation, which means that the BFR-SS is usually not monitored. Always counting the candidates of BFR-SS that may never be monitored seems overkill, thus overbooking can be applied once the BFR-SS is activated.

Observation 1: BFR should be considered as an exception case rather than a regular operation, thus always counting the candidates of BFR-SS that may never be monitored seems overkill.

If overbooking is applied, it is obviously that the BFR-SS should have a higher priority than other UE-specific search space sets, and even higher than common search space sets. One straightforward solution is to map the BFR-SS before any other SS sets (i.e. assigning it a highest priority). But such a solution imposes undesirable specification impacts at this late stage.

On the other hand, implementation-based solutions can be considered. Firstly, the BFR-SS can be configured with a lowest SS ID, so that it is always mapped before any other USS. Alternatively, according to the current specification [2], it is allowed to configure the BFR-SS as a CSS that is always mapped during overbooking, though only fallback DCI can be monitored. Both solutions have some restrictions; nevertheless, they can resolve this issue without specification impact.

Proposal 1: The BFR-SS can be prioritized in search space mapping by network configuration, e.g. by assigning a lowest USS ID or configuring as a CSS.

3. BD/CCE limit for CA case

The BD/CCE limit for CA case has been discussed in the RAN1#93 meeting and the following agreements have been achieved [3].

Agreements:

- For following, regardless of whether one or more numerologies, the limit of BDs/CCEs per CC per slot is equal to the limit of BDs/CCEs for non-CA case.
 - Self-scheduling with up to 4 DL-CCs
 - Self-scheduling with up to T DL-CCs where the UE reports BD capability of $y \geq T$
 - ✧ y is integer from (4, ..., 16)
 - ✧ T is integer from (1, ..., 16)
- For cross-carrier scheduling where the scheduling CC and all the CCs schedulable by the scheduling CC have the same numerology and the number of DL-CCs is up to 4 or with up to T DL-CCs where the UE reports BD capability of $y \geq T$, the limit of BDs/CCEs of the scheduling CC per slot is (the number of CCs schedulable by the scheduling CC) x (the limit of BDs/CCEs for non-CA case)
 - Note: this is inline with the previous agreements at RAN1#92bis meeting

Agreements:

- For self-scheduling with the same numerology or different numerologies, and the number of DL-CCs is ≤ 4 or with up to T DL-CCs where the UE reports BD capability of $y \geq T$, network ensures the number of BDs/CCEs on any SCell does not exceed the non-CA limit.

Agreements:

- For self-scheduling with same numerology, and the number of DL-CCs is more than 4 and with up to T DL-CCs where the UE reports BD capability of $y < T$, the limit of BDs/CCEs per CC per slot is
 - ✧ The total number of BDs/CCEs across CCs is based on UE BD capability. It can be split across CCs, subject to the non-CA limit on each CC.
 - For SCell, NW ensures no overbooking based on non-CA case occurs.

Agreements:

- For UE BD capability reporting $y = \text{integer}(4, \dots, 16)$, at least for self-scheduling,
 - For UE not supporting CA with different numerologies, the reported value equally applies to all numerologies
 - (Working assumption) For UE supporting CA with different numerologies,
 - When the UE is configured with CA with the same numerology, the reported value applies
 - When the UE is configured with CA with different numerologies, the reported value applies to each set of DL-CCs with the same numerology, i.e.:
 - If a UE is configured with DL-CCs of X_0, X_1, X_2, X_3 , where X_i denotes the number of DL-CCs with the numerology i, the **limit total-number** of (BDs or CCEs) for the DL-CCs with the numerology i is given by $\text{Floor}\{X_i / (X_0 + X_1 + X_2 + X_3) * (M_i \text{ or } N_i) * y\}$ per slot of the numerology i
 - Where M_i and N_i represent the number of BDs and CCEs per slot specified for non-CA case, respectively
 - Note: some of the values of X_i may be zero depending on the CA

- For each CC, the non-CA limit still applies
- FFS the impact of BWP, if any

Agreements:

- For self-scheduling with different numerologies, and the number of DL-CCs is more than 4 and with up to T DL-CCs where the UE reports BD capability of $y < T$, the limit of BDs/CCEs per CC per slot is
 - (Working assumption) The total number of BDs/CCEs across CCs per numerology is based on UE BD capability. It can be split across CCs for the given numerology, subject to the non-CA limit on each CC.
 - If a UE is configured with DL-CCs of X0, X1, X2, X3, where Xi denotes the number of DL-CCs with the numerology i, the limit of (BDs or CCEs) for the DL-CCs with the numerology i is given by $\text{Floor}\{X_i / (X_0 + X_1 + X_2 + X_3) * (M_i \text{ or } N_i) * y\}$ per slot of the numerology i
- For SCell, NW ensures no overbooking based on non-CA case occurs

However, there are still some open issues on determining the BD/CCE limit in the following cases:

1. the SCS is changed due to active BWP change
2. one of the SCell become deactivated or activated

In the following section we provide our view on these issues.

3.1. Active BWP switching

According to the specification, the number of BD/CCE limit is determined by the SCS of the serving cell. However, if more than one BWP with different SCSs are configured, it is not clear from the specification which SCS is considered as the active SCS of the serving cell. Basically there are two alternatives:

Alt-1: based on the SCS of the active BWP

Alt-2: based on the SCS of a configured BWP regardless whether it is activated or not

Alt-1 is a more straightforward and optimal choice. Alt-2 may seem to be simpler, from the perspective that the BD/CCE limit may not be recalculated due to the SCS change during dynamic BWP change. However, it should be noted that CORESET and search space sets are configured per BWP, and the numbers of BD/CCE for each BWP are anyway BWP-specific. Then, no matter the SCSs across BWPs are changed or not, the BD/CCE are always recalculated. Consequently, Alt-2 brings additional restrictions, however, does not reduce the complexity. Therefore, Alt-1 is preferred.

Observation 2: *No matter the SCSs across BWPs are different or not, the BD/CCE are always recalculated in case of BWP switching.*

Proposal 2: *The active SCS of the serving cell for BD/CCE limit calculation is determined based on the SCS of the active BWP of the cell.*

In this case, if the active BWP is changed to another one with different SCS, the number of BD/CCE limit is changed, too. During the transition time of BWP switching, it may be ambiguous on which SCS is used to determine the BD/CCE limit. This is not a problem in the non-CA case, because UE is not expected to receive DL signals or transmit UL signals during the transition time.

However, this ambiguity may become an issue in the CA case. Although the UE may not monitor PDCCH for the cell of which SCS is being changed, the UE should still monitor the other cells. The numbers of BD/CCE limit of these cells are determined by the SCS of all the cells, including the one being changed. Consequently, during the transition time of BWP switching of one cell, it may be ambiguous on what the numbers of BD/CCE limit are, as well as how the search spaces map, on all the other cells.

Observation 3: *During the transition time of BWP switching of one cell, it may be ambiguous on the BD/CCE limit and search space mapping on all the other cells.*

Therefore, it is proposed to clarify the UE behavior during the transition time of BWP switching. For example, the BD/CCE limit and search space mapping of all the cells are not changed until the slot or symbol that the new BWP of the switching cell become valid.

Proposal 3: If the active BWP SCS of one cell is changed, the UE should retain the number of BD/CCE limit and the search space mapping for all the other cells, until the slot/symbol that the new BWP of the switching cell become valid.

3.2. SCell activation/deactivation

According to the specification [4], the UE determines the BD/CCE limit, and consequently the search space mapping/dropping, by the number of *configured downlink cells*, i.e. the $N_{\text{cells}}^{\text{DL},\mu}$ as highlighted below.

If a UE is capable for operation with carrier aggregation with more than 4 downlink cells, and the UE indicates through *pdccch-BlindDetectionCA* a capability to monitor PDCCH candidates for $N_{\text{cells}}^{\text{cap}} \geq 4$ downlink cells, and the UE is configured with $N_{\text{cells}}^{\text{DL},\mu}$ with subcarrier spacing configuration μ , and for scheduling on a same cell, the UE is expected to be able to monitor a total of

$$M_{\text{PDCCH}}^{\text{total},\mu} = \min \left\{ N_{\text{cells}}^{\text{DL},\mu} \cdot M_{\text{PDCCH}}^{\text{max,slot},\mu}, \left\lfloor N_{\text{cells}}^{\text{cap}} \cdot M_{\text{PDCCH}}^{\text{max,slot},\mu} \cdot N_{\text{cells}}^{\text{DL},\mu} / \sum_{\mu=0}^3 N_{\text{cells}}^{\text{DL},\mu} \right\rfloor \right\} \text{ PDCCH candidates for DCI formats}$$

with different size and/or different corresponding DM-RS scrambling sequences per slot over the $N_{\text{cells}}^{\text{DL},\mu}$ cells with subcarrier spacing configuration μ , and a total of

$$C_{\text{PDCCH}}^{\text{total},\mu} = \min \left\{ N_{\text{cells}}^{\text{DL},\mu} \cdot C_{\text{PDCCH}}^{\text{max,slot},\mu}, \left\lfloor N_{\text{cells}}^{\text{cap}} \cdot C_{\text{PDCCH}}^{\text{max,slot},\mu} \cdot N_{\text{cells}}^{\text{DL},\mu} / \sum_{\mu=0}^3 N_{\text{cells}}^{\text{DL},\mu} \right\rfloor \right\} \text{ non-overlapped CCEs per slot over the}$$

$N_{\text{cells}}^{\text{DL},\mu}$ cells with subcarrier spacing configuration μ . The maximum number of PDCCH candidates for DCI formats with different size and/or different corresponding DM-RS scrambling sequences and the maximum number of non-overlapped CCEs per slot and per cell of the $N_{\text{cells}}^{\text{DL},\mu}$ cells are $M_{\text{PDCCH}}^{\text{max,slot},\mu}$ and $C_{\text{PDCCH}}^{\text{max,slot},\mu}$, respectively.

If the UE is configured with a total of $N_{\text{cells}}^{\text{DL},\mu}$ downlink cells with same subcarrier spacing configuration μ or if the UE indicates through *pdccch-BlindDetectionCA* a capability to monitor PDCCH candidates for $N_{\text{cells}}^{\text{cap}} \geq 4$ downlink cells then, for cross-carrier scheduling over the $N_{\text{cells}}^{\text{DL},\mu}$ downlink cells with same subcarrier spacing configuration μ , including the scheduling cell, the UE is expected to monitor $\min(N_{\text{cells}}^{\text{DL},\mu}, N_{\text{cells}}^{\text{cap}}) \cdot M_{\text{PDCCH}}^{\text{max,slot},\mu}$ PDCCH candidates for DCI formats with different size per slot on the scheduling cell and $\min(N_{\text{cells}}^{\text{DL},\mu}, N_{\text{cells}}^{\text{cap}}) \cdot C_{\text{PDCCH}}^{\text{max,slot},\mu}$ non-overlapped CCEs per slot on the scheduling cell.

As the UE would never monitor the PDCCH of the deactivated cell, the number of BD/CCE candidates preserved for the deactivated cell are wasteful. It is better to determine the BD/CCE limit by the activated downlink cells, instead of the configured downlink cells.

Moreover, it is worth noting that, if the limit is determined by the active BWP numerology, then the behavior for BWP numerology changing may also be applied to SCell activation/deactivation. The processing cost may not be a concern, because the SCell activation/deactivation is triggered by MAC CE, which would be significantly slower than that of BWP switching triggered by DCI.

Proposal 4: The UE determines the BD/CCE limit, as well as the search space mapping, by the number of activated downlink cells, instead of the configured downlink cells.

Another issue is that, the UE monitors the PDCCH only if the SCell is activated. An issue similar to active BWP switching would occur, i.e. the activation and deactivation on one SCell would impact the PDCCH monitoring behaviors of the other cells. Then the PDCCH monitoring behaviors on the cells are ambiguous during the transition time of SCell activation/deactivation. The similar clarification for active BWP switching is also needed for SCell activation/deactivation.

Proposal 5: If a SCell is being activated or deactivated, the UE should retain the number of BD/CCE limit and the search space mapping for all the other cells, until the slot that the new cell activation state become valid.

4. Simultaneous reception of channels

The issue of simultaneous reception of multiple channels with different spatial QCL assumptions was discussed in MIMO section. It is proposed in [5] to discuss the following cases in control section:

1. Simultaneous reception of PDCCHs with different spatial QCL assumptions
2. Simultaneous reception of PDSCHs with different spatial QCL assumptions

In the following sections we provide our view on these issues.

4.1. Simultaneous reception of PDCCHs

If a UE is configured with multiple search space sets associated with different CORESETs, and each of them is configured and activated with a distinct TCI state, in the case of the monitoring occasions of the search spaces are overlapped in time, the UE may not be able to monitor all the CORESETs. Three solutions are proposed in [6] for this issues:

- Option-1: Monitoring skips of lower prioritized CORESET.
- Option-2: TCI state of the CORESET with lowest CORESET-ID is applied for overlapped CORESETs.
- Option-3: No overlap between CORESETs with different spatial QCLs occurs.

Option-1 require additional rule for defining priority of CORESET, which may complicate the UE implementation. Moreover, it may further increase the PDCCH blocking rate due to reduced scheduling possibility. Therefore, option-1 is not preferable.

Option-2 does not have the above-mentioned issues, however, introduces issues in other aspects. Firstly, it is not clear which TCI state would be applied, if the CORESET with lowest ID among the overlapped CORESETs were not configured with TCI states (e.g. CORESET #0 or *commonControlResourceSet* provided by *SIB1*). Secondly, in the case of simultaneous reception during beam failure recovery procedure, i.e. one of the overlapped CORESET is associated to BFR-SS, if the BFR CORESET is *not* configured with the lowest ID, the UE would fail to complete the recovery procedure using the wrong TCI state. Furthermore, the simultaneous reception issue may also happens for CA case, if the UE does not have multiple Rx beam for each carrier (e.g. intra-band CA). In this case, the overlapping CORESET of different carriers may have the same CORESET ID, then additional rule is needed to further clarify which TCI should be used (for example, the CORESET with lowest ID in carrier with lowest CC index, etc.). Consequently, significant specification impacts are needed for option-2, which is not favorable in this late stage.

Option-3 is the simplest solution and has no specification impact. Although there may be some potential scheduling restriction, it is acceptable in this release.

Proposal 6: A UE is not expected to monitor multiple PDCCHs or CORESETs with different TCI overlapping in time.

4.2. Simultaneous reception of PDSCHs

Similar to the case of PDCCH, a UE may not be able to simultaneously receive multiple PDSCH overlapping in time. In the case of PDSCHs scheduled by different RNTIs (e.g. SI-RNTI, C-RNTI, MCS-C-RNTI, CS-RNTI, etc.), it is natural to prioritize the reception based on the RNTI.

In the case of multiple PDSCHs with different TCI states scheduled by the same RNTI, e.g. in CA case where PDSCHs from different carriers overlapping, it can be seen as an error case, assuming that the scheduler can avoid this situation.

Proposal 7: In the case of simultaneous reception of multiple PDSCHs with different TCI states, the UE prioritizes the reception based on the RNTI; UE is not expected to receive multiple PDCCHs with different TCI states scheduled by the same RNTI.

5. Conclusion

In the contribution, we discussed the remaining issues on PDCCH and observe that,

Observation 1: BFR should be considered as an exception case rather than a regular operation, thus always counting the candidates of BFR-SS that may never be monitored seems overkill.~~Observation 1: BFR should be considered as an exception case rather than a regular operation, thus always counting the candidates of BFR-SS that may never be monitored seems overkill.~~

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Observation 2: No matter the SCSs across BWPs are different or not, the BD/CCE are always recalculated in case of BWP switching.~~Observation 2: No matter the SCSs across BWPs are different or not, the BD/CCE are always recalculated in case of BWP switching.~~

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Observation 3: During the transition time of BWP switching of one cell, it may be ambiguous on the BD/CCE limit and search space mapping on all the other cells.~~Observation 3: During the transition time of BWP switching of one cell, it may be ambiguous on the BD/CCE limit and search space mapping on all the other cells.~~

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Based on these observations, we propose that,

Proposal 1: The BFR-SS can be prioritized in search space mapping by network configuration, e.g. by assigning a lowest USS ID or configuring as a CSS.~~Proposal 1: The BFR-SS can be prioritized in search space mapping by network configuration, e.g. by assigning a lowest USS ID or configuring as a CSS.~~

Proposal 2: The active SCS of the serving cell for BD/CCE limit calculation is determined based on the SCS of the active BWP of the cell.~~Proposal 2: The active SCS of the serving cell for BD/CCE limit calculation is determined based on the SCS of the active BWP of the cell.~~

Proposal 3: If the active BWP SCS of one cell is changed, the UE should retain the number of BD/CCE limit and the search space mapping for all the other cells, until the slot/symbol that the new BWP of the switching cell become valid.~~Proposal 3: If the active BWP SCS of one cell is changed, the UE should retain the number of BD/CCE limit and the search space mapping for all the other cells, until the slot/symbol that the new BWP of the switching cell become valid.~~

Proposal 5: If a SCell is being activated or deactivated, the UE should retain the number of BD/CCE limit and the search space mapping for all the other cells, until the slot that the new cell activation state become valid.~~Proposal 5: If a SCell is being activated or deactivated, the UE should retain the number of BD/CCE limit and the search space mapping for all the other cells, until the slot that the new cell activation state become valid.~~

Proposal 4: The UE determines the BD/CCE limit, as well as the search space mapping, by the number of activated downlink cells, instead of the configured downlink cells.~~Proposal 4: The UE determines the BD/CCE limit, as well as the search space mapping, by the number of activated downlink cells, instead of the configured downlink cells.~~

Proposal 6: A UE is not expected to monitor multiple PDCCHs or CORESETs with different TCI overlapping in time.~~Proposal 6: A UE is not expected to monitor multiple PDCCHs or CORESETs with different TCI overlapping in time.~~

Proposal 7: In the case of simultaneous reception of multiple PDSCHs with different TCI states, the UE prioritizes the reception based on the RNTI; UE is not expected to receive multiple PDCCHs with different TCI states scheduled by the same RNTI.~~Proposal 7: In the case of simultaneous reception of multiple PDSCHs with different TCI states, the UE prioritizes the reception based on the RNTI; UE is not expected to receive multiple PDCCHs with different TCI states scheduled by the same RNTI.~~

6. Reference

- [1] Chairman's Notes, 3GPP TSG RAN WG1 meeting#94.
- [2] 3GPP TS 38.331, "Radio Resource Control (RRC) protocol specification", V15.2.1.
- [3] Chairman's Notes, 3GPP TSG RAN WG1 meeting#93
- [4] 3GPP TS 38.213, "Physical layer procedures for control", V15.2.0.

- [5] R1-1809882, “Guidance on simultaneous reception of channels or RS”, Intel Corporation, Gothenburg, Aug 2018.
- [6] R1-1809766, “PDCCH monitoring for cross-carrier scheduling”, NTT DOCOMO, INC., Gothenburg, Aug 2018.