3GPP TSG RAN WG1 Meeting #90bis **R1-1717062**
Prague, Czech Republic, 9 – 13 October 2017

Agenda Item: **7.3.1.2**
Source: **Huawei, HiSilicon**
Title: **CORESET configuration and search space design**
Document for: **Discussion and decision**

1 Introduction

In the previous meetings, some agreements related to CORESET configuration and search space design [1][2][3][4] were achieved as shown in Appendix A. The contribution mainly provides some further considerations on CORESET configuration and search space design.

2 Discussion

2.1 CORESET Configuration

2.1.1 CORESET for initial access

<u>CORESET for RMSI</u>

During initial access, it is agreed that a CORESET with common search space should be available for at least scheduling of RMSI, i.e. RMSI CORESET. It was also agreed that at least TDM between the SS block and the CORESET is supported. Based on the agreements, one CORESET candidate position could be that the CORESET occupies the two OFDM symbols ahead of PSS, in the same PRBs occupied by the SS block. This is beneficial for some typical scenarios where the system BW is strictly limited, e.g., 5 MHz, as shown in Figure 1.

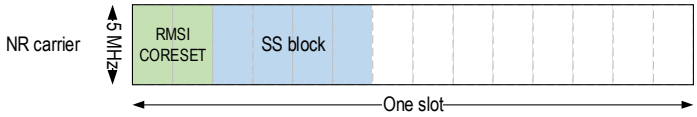

Figure 1 CORESET location in the case with 5 MHz system BW

This option can be extended to some other scenarios where the CORESET is configured central aligned with the SS block but with a different numerology and/or BW. The duration of the CORESET can be configurable accordingly. For example, 1 OFDM symbol can be configured when the CORESET BW is sufficiently large, e.g., 48 PRBs.

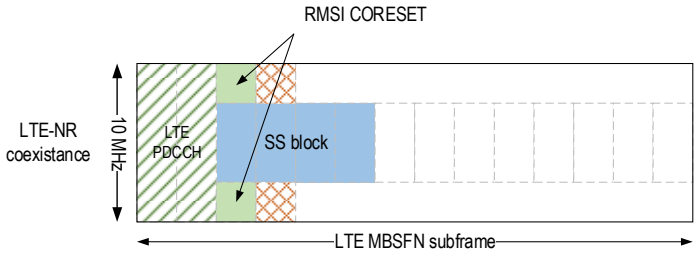

Figure 2 CORESET location in the case with LTE-NR coexistence

There remains an FFS on whether FDM between the SS block and the CORESET should be supported. From our points of view, the following benefits can be achieved by supporting this option where the CORESET and SS block are located in the same OFDM symbols. One benefit is to better support beam sweeping which can simplify UE behavior related to PDCCH monitoring during initial access. The other benefit is from the potential requirements of LTE-NR coexistence. As shown in Figure 2, the first two OFDM symbols are reserved for LTE UE to receive LTE CRS. Therefore, another candidate CORESET

position could be that the CORESET is in the same OFDM symbol as PSS and with equal number PRBs below and above SS block in frequency.

Note that this option can also be extended to some other scenarios where the CORESET are configured with a different numerology and/or BW from that (those) of SS block.

Moreover, during RAN1#90 meeting, it was agreed that an initial active DL BWP is configured for UE during initial access and such DL BWP is confined within the UE minimum bandwidth for the given frequency band. There is likely a common understanding that such DL BWP contains both CORESET and PDSCH for RMSI.

Based on the above discussions and take sub 6 GHz frequency band as instance, the following table can be considered as the starting points for RMSI CORESET configuration. Note that the minimum UE bandwidth for sub 6 GHz frequency band is assumed to be 20 MHz.

Table 1 An example of candidate configurations of CORESET for scheduling RMSI

Bit field in NR-PBCH	CORESET configuration
00000	CORESET BW = 24 PRBs; CORESET occupies the 1st and 2nd OFDM symbols in the same slot and in the same PRBs occupied by the SS block; CORESET uses SCS = 15 kHz.
00001	CORESET BW = 24 PRBs; CORESET occupies the 7th and 8th OFDM symbols in the same slot and in the same PRBs occupied by SS block; CORESET uses SCS = 15 kHz.
00010	CORESET BW = 48 PRBs; CORESET occupies the 1st OFDM symbols in the same slot and with the center of CORESET BW aligned with the center of SS block; CORESET uses SCS = 15 kHz.
00011	CORESET BW = 48 PRBs; CORESET occupies the 2nd OFDM symbols in the same slot and with the center of CORESET BW aligned with the center of SS block; CORESET uses SCS = 15 kHz.
00100	CORESET BW = 96 PRBs; CORESET occupies the 1st OFDM symbols in the same slot and in the continuous PRBs within 20MHz; CORESET uses SCS = 15 kHz.
00101	CORESET BW = 96 PRBs; CORESET occupies the 2nd OFDM symbols in the same slot and in the continuous PRBs within 20MHz; CORESET uses SCS = 15 kHz.
00110	CORESET BW = 24 PRBs; CORESET occupies the 1st OFDM symbol in the same slot and in the same PRBs occupied by the SS block; CORESET uses SCS = 15 kHz.
00111	CORESET BW = 24 PRBs; CORESET starts with the same OFDM symbol as PSS and with equal number of PRBs below and above the SS block in frequency; CORESET uses SCS = 15 kHz.
01000	CORESET BW = 48 PRBs; CORESET starts with the same OFDM symbol as PSS and with equal number of PRBs below and above the SS block in frequency; CORESET uses SCS = 15 kHz.
01001	CORESET BW = 24 PRBs; CORESET occupies the 1st and 2nd OFDM symbols in the same slot and in the discontinuous PRBs with interval of 4 PRBs; CORESET uses SCS = 15 kHz.
01010	CORESET BW = 24 PRBs; CORESET occupies the 7th and 8th OFDM symbols in the same slot and in the discontinuous PRBs with interval of 4 PRBs; CORESET uses SCS = 15 kHz.
01011	CORESET BW = 48 PRBs; CORESET occupies the 1st and 2nd OFDM symbols in the same slot and in the discontinuous PRBs with interval of 2 PRBs; CORESET uses SCS = 15 kHz.

01100	CORESET BW = 48 PRBs; CORESET occupies the 7th and 8th OFDM symbols in the same slot and in the discontinuous PRBs with interval of 2 PRBs; CORESET uses SCS = 15 kHz.
01101	CORESET BW = 24 PRBs; CORESET occupies the 1st and 2nd OFDM symbols in the same slot and in the same PRBs occupied by the SS block; CORESET uses SCS = 30 kHz.
01110	CORESET BW = 24 PRBs; CORESET occupies the 3rd and 4th OFDM symbols in the same slot and in the same PRBs occupied by the SS block; CORESET uses SCS = 30 kHz.
01111	CORESET BW = 48 PRBs; CORESET occupies the 1st OFDM symbols in the same slot and with the center of CORESET BW aligned with the center of SS block; CORESET uses SCS = 30 kHz.
10000	CORESET BW = 48 PRBs; CORESET occupies the 2nd OFDM symbols in the same slot and with the center of CORESET BW aligned with the center of SS block; CORESET uses SCS = 30 kHz.
10001	CORESET BW = 24 PRBs; CORESET occupies the 2nd OFDM symbol in the same slot and in the same PRBs occupied by the SS block; CORESET uses SCS = 15 kHz.
10010	CORESET BW = 24 PRBs; CORESET occupies the 1st and 2nd and 3rd OFDM symbols in the same slot and in the same PRBs occupied by the SS block; CORESET uses SCS = 30 kHz.
10011	CORESET BW = 24 PRBs; CORESET starts with the same OFDM symbol as PSS and with equal number of PRBs below and above the SS block in frequency; CORESET uses SCS = 30 kHz.
10100	CORESET BW = 24 PRBs; CORESET occupies the 1st and 2nd OFDM symbols in the same slot and in discontinuous PRBs with interval of 4 PRBs; CORESET uses SCS = 30 kHz.
10101	CORESET BW = 48 PRBs; CORESET occupies the 1st and 2nd OFDM symbols in the same slot and in the continuous PRBs within 20MHz; CORESET uses SCS = 30 kHz.
10110	CORESET BW = 24 PRBs; CORESET occupies the 1st and 2nd OFDM symbols in the same slot and with the center of CORESET BW aligned with the center of SS block; CORESET uses SCS = 60 kHz.
10111	CORESET BW = 24 PRBs; CORESET occupies the 1st OFDM symbols in the same slot and with the center of CORESET BW aligned with the center of SS block; CORESET uses SCS = 60 kHz.
11000	CORESET BW = 24 PRBs; CORESET occupies the 2nd OFDM symbols in the same slot and with the center of CORESET BW aligned with the center of SS block; CORESET uses SCS = 60 kHz.
11001	CORESET BW = 24 PRBs; CORESET occupies the 1st OFDM symbol in the same slot and in the same PRBs occupied by the SS block; CORESET uses SCS = 30 kHz.
11010	CORESET BW = 24 PRBs; CORESET occupies the 2nd OFDM symbol in the same slot and in the same PRBs occupied by the SS block; CORESET uses SCS = 30 kHz.
11011	CORESET BW = 24 PRBs; CORESET occupies the 2 OFDM symbols in the same slot and with the center of CORESET BW aligned with the center of SS block; CORESET uses SCS = 15 kHz.
11100	CORESET BW = 24 PRBs; CORESET occupies the 1 OFDM symbols in the same slot with the center of CORESET BW aligned with the center of SS block; CORESET uses SCS = 15 kHz.
11101	CORESET BW = 48 PRBs; CORESET occupies the 1 OFDM symbols in the same slot with the center of CORESET BW aligned with the center of SS block; CORESET uses SCS = 30 kHz.

11110	CORESET BW = 24 PRBs; CORESET occupies the 1 OFDM symbols in the same slot with the center of CORESET BW aligned with the center of SS block; CORESET uses SCS = 60 kHz.
11111	Reserved

Proposal 1: *The candidate configurations provided in Table 1 can be the starting point for configuration of the CORESET for scheduling RMSI.*

In order to enable PBCH combination, the time-domain position of CORESET for RMSI for some candidate configuration(s) (e.g. the last four candidate configurations in Table 1) can be derived implicitly according to the location of SS/PBCH block, because no explicit indication of the location of RMSI CORESET will facilitate PBCH combination without too much difference bits. Potential time-domain locations for multiple SS blocks within a slot were agreed in [2][1], with each associated with a beam. In time-domain, the location of the CORESET can be associated with the time-domain location of the QCLed SS/PBCH block.

In addition, in order to further reduce the bit length carried by MIB for configuration of RMSI CORESET, part of indication can be implicitly indicated also, e.g. the time-domain position of CORESET for RMSI can be predefined or derived implicitly according to the location of SS/PBCH block.

<u>CORESET for OSI and paging</u>

As was agreed that the configuration of CORESET for RAR is contained in RACH configuration, it is natural to adopt the similar solution for the independent configurations of the CORESET(s) for other system information (OSI) and paging from the CORESET of RMSI. These independent configurations can be carried in RMSI in order to provide good flexibility and extend the search space capacity for delivering these broadcast or group common information [5].

Proposal 2: *RMSI can be used to indicate a CORESET for other system information, paging, etc.*

2.1.2 CORESET after initial access

In RAN1 meeting #88bis, it has been agreed that *monitoring periodicity is configured for a CORESET by UE-specific higher-layer signaling*. Default monitoring periodicities should be defined in specification in case the configuration of monitoring periodicity is not available. Such default value can be set as e.g., every slot for slot-level scheduling, every symbol or every second symbol for mini-slot-level scheduling. To address the problem of an ambiguous period, a fallback monitoring periodicity is also needed. One alternative is to allow the UE fall back to the default value, and the other one is to allow the UE fallback to the previous configured value. In addition, as described in [6], the DCI for slot-based scheduling and the DCI for non-slot based scheduling could have different monitoring periodicities, where the monitoring periodicity for DCI for slot-based scheduling can be in the granularity of slot, while the monitoring periodicity for DCI for non-slot based scheduling can be in the granularity of symbol(s).

Proposal 3: *Default monitoring periodicities should be predefined for monitoring PDCCH.*

Since a NR-CCE is defined as 6 REGs, it is straightforward to consider the number of PRBs for a CORESET in the frequency domain equals to $6\times K$, where K is a positive integer. In RAN1 Meeting NR-AH#3, the following working assumption is reached: *re-use NR DL RA type 0 basis in units of 6 RBs, where no restriction on the maximum number of segments for a given CORESET*. It is beneficial to confirm this working assumption. Firstly, flexibility on the resource allocation in frequency domain for CORESET could be achieved. Secondly, by using the same resource allocation mechanism for data, it could enable efficient resource utilization between control and data.

Proposal 4*: Confirm the working assumption: Re-use NR DL RA type 0 basis in units of 6 RBs, where no restriction on the maximum number of segments for a given CORESET.*

In [2], it has been agreed that *at least one of configured DL BWPs includes one CORESET with common search space at least in primary component carrier* and *each configured DL BWP include at least one CORESET with UE-specific search space for the case of single active BWP at a given time*. One alternative

based on such agreements is to configure BWP according to the UE bandwidth capability containing a common CORESET for initial access. This, however, may cause impact on resource efficiency since UEs always need to retune to the common CORESET. An alternative to solve this problem is to configure additional CORESET containing common search spaces to UEs respectively in one of their configured BWPs. Dedicated RRC signaling can be considered to transmit the configuration signaling. REG bundle size/pattern, CCE-to-REG mapping (i.e., time-first or frequency-first), transmission type (i.e., interleaved or non-interleaved), and numerology for the common CORESET(s) can be configurable.

Proposal 5*: Additional CORESET(s) with common search space(s) can be configured by UE-specific RRC signaling.*

2.2 Search space design

2.2.1 Sparsely nested structure

As an agreement, in NR-PDCCH design, to reduce the efforts on channel estimation for the UE, *the channel estimation obtained for one RE should be reusable across multiple blind decodings involving that RE in at least the same control resource set and type of search space (common or UE-specific)*. Therefore, for either common search spaces or UE-specific search spaces, PDCCH candidates between different aggregation levels could overlap with each other as much as possible. Specifically, PDCCH candidates for higher aggregation level may contain CCEs of PDCCH candidates for lower aggregation level. One example is shown in Figure 3, the starting position of all aggregation levels are aligned with each other within the continuously nested search space structure.

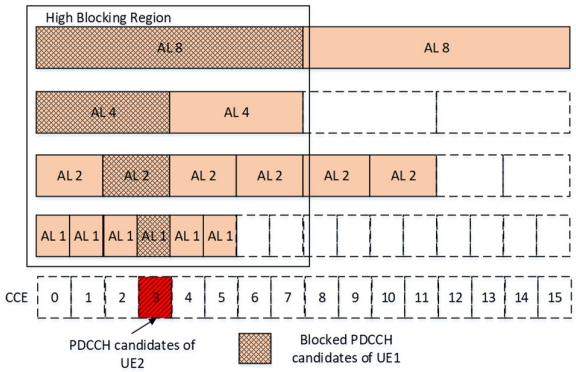

Figure 3 Continuously nested structure of search spaces.

The blocking probability will be increased for a nested search space structure as shown in Figure 3. As shown in Figure 3, there exists a high blocking region where one occupied CCE will block multiple candidates with different aggregation levels. As an example, if UE1's search spaces are depicted as shown in Figure 3 and a PDCCH candidate of UE2 occupies CCE#3, 4 PDCCH candidates of UE1 are blocked. In addition, according to the evaluation as discussed in [7] and as shown in Appendix B, the continuously nested structure of search space increases block probability compared with LTE PDCCH.

In order to reduce the number of blocked candidates, the linkage between two candidates with different aggregation levels should be relaxed. It means that the blocking should not impact on candidates of all other aggregation levels. One possible solution is that candidates with lower aggregation levels can be nested sparsely (i.e. PDCCH candidates located non-contiguously and non-uniformly) within the resources of candidates with higher aggregation levels as shown in Figure 4. As shown in Appendix B, sparsely nested structure has lower blocking probability compared to continuously nested structure and could achieve similar blocking probability as LTE.

Observation 1: *Sparsely nested structure of search space has lower blocking probability compared with continuously nested structure of search spaces.*

In order to further consider the scheduling gain for PDCCH candidates, particularly for non-interleaving CCE-REG mapping, the PDCCH candidates with the highest aggregation level could also be located in

non-contiguous way. Accordingly, the PDCCH candidates with lower aggregation levels are sparsely nested within CCEs of the search space with the largest aggregation level as shown in Figure 4.

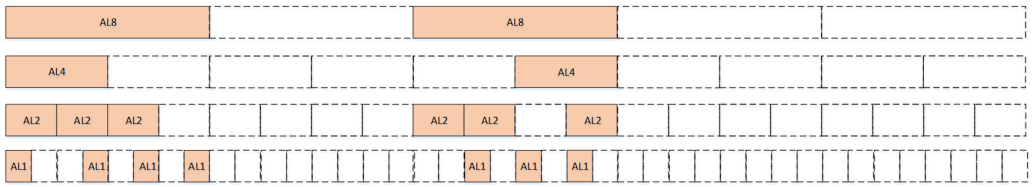

Figure 4 Sparsely nested structure of search spaces.

2.2.2 Determination of CCEs for search spaces

For the nested search space structure, the following principle could be used to determine a UE's search space, firstly the CCEs corresponding to the highest aggregation level could be determined, then the CCEs corresponding to lower aggregation level can be further determined within the CCEs corresponding to the highest aggregation level.

<u>Determination of CCEs for search space at the highest aggregation level</u>

For the highest aggregation level, PDCCH candidates will be distributed across the CORESET non-contiguously to obtain scheduling gain. Similar as EPDCCH, the CCEs corresponding to PDCCH candidate m^H of the search space at the highest aggregation level are given by (1):

$$L_{\max}\left\{(Y_k + f(m^H))mod\left\lfloor\frac{N_{\mathrm{CCE}}}{L_{\max}}\right\rfloor\right\} + i, \tag{1}$$

where Y_k denotes a random position shift for all PDCCH candidates, $i \in \{0,1,2,\dots,L_{\max}-1\}$, and $m^H \in \{0,1,2,\dots,M^{(L_{\max})}-1\}$, $M^{(L_{\max})}$ is the number of PDCCH candidates with the maximum AL. If EPDCCH manner is used, then $f(m^H) = \left\lfloor\frac{m^H \cdot N_{\mathrm{CCE}}}{L_{\max} \cdot M^{(L_{\max})}}\right\rfloor$, which will result in that PDCCH candidates are distributed uniformly within the CORESET. Another alternative is to enable non-uniform distribution of PDCCH candidates within the CORESET, which could reduce the blocking probability. In this case, $f(m^H) = \alpha \cdot m^H$, where the value of α can be configured explicitly or derived implicitly which will determine the gap between two PDCCH candidates with consecutive candidate index, the GCD (Greatest common divisor) between the value of α and $\left\lfloor\frac{N_{\mathrm{CCE}}}{L_{\max}}\right\rfloor$ equals to 1, and α is not close to 1 and $\left\lfloor\frac{N_{\mathrm{CCE}}}{L_{\max}}\right\rfloor$. For example, if $\left\lfloor\frac{N_{\mathrm{CCE}}}{L_{\max}}\right\rfloor = 5$, then α can be 2 or 3.

<u>Determination of CCEs for search space at lower aggregation level</u>

For lower aggregation levels, the PDCCH candidates only occupy the CCEs within the set of CCEs corresponding to the PDCCH candidates of the highest aggregation level. The CCEs corresponding to PDCCH candidate m of the search space at a lower aggregation level are given by

$$L\{W_k + g(m)\}mod\left\lfloor\frac{L_{\max}}{L}\right\rfloor + l_{m^H} + i, \tag{2}$$

Where $L < L_{max}$, W_k is the random factor for lower aggregation levels, which can be derived based on similar formula for Y_k but different values should be used, $i \in \{0,1,2,\dots,L-1\}$. Similar as (m^H), $g(m) = \beta \cdot m$, where the value of β can be configured explicitly or derived implicitly which will determine the gap between two PDCCH candidates with consecutive candidate index and satisfies $\mathrm{GCD}\left(\beta, \left\lfloor\frac{M^{(L_{\max})} \cdot L_{\max}}{L}\right\rfloor\right) = 1$. As a result, the value of β determines the randomized location pattern of PDCCH candidates. l_{m^H} is the starting CCE index of PDCCH candidate m^H at the highest aggregation level, where the relationship between m^H and m should enable the PDCCH candidates at the lower

aggregation level is located within all the PDCCH candidates at the highest aggregation level as shown in Figure 5, where $\beta = 5$ and $W_k = 0$, the lower aggregation level is 2.

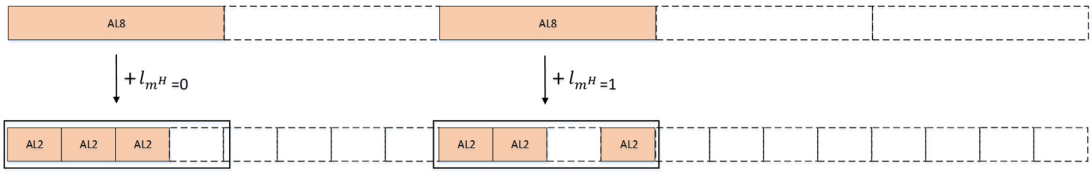

Figure 5 Position pattern of PDCCH candidates with the AL 2 and $g(m) = 5 \cdot m$.

As to the value of Y_k and W_k, similar design principle used in LTE can be reused. That is, it can be given by a function of several parameters, such as slot index and a configurable UE-specific ID, where the configurable UE-specific ID comes from some potential considerations from multi-TRP distributed non-coherent JT and UE's C-RNTI is seen as a default value if not for multi-TRP case. Additionally, in LTE EPDCCH a set-specific random parameter $Y_{p,k}$ is used to determine the first ECCE of a candidate in each set. This is because that randomizing the location of PDCCH candidates in different CORESETs can also reduce the blocking probability. Consequently, it would be beneficial to adopt the same principle.

Proposal 6: *When CCEs corresponding to a search space with higher aggregation level contains CCEs corresponding to a search space with lower aggregation level*

- *The PDCCH candidates with the highest aggregation level should be located non-contiguously.*
- *The PDCCH candidates with lower aggregation level should be located non-contiguously and non-uniformly within the set of CCEs corresponding to the PDCCH candidates at the highest aggregation level.*
- *The CCEs corresponding to the search space with lower aggregation level is associated with the UE's C-RNTI/a configurable UE-specific ID.*

2.2.3 DCI blind decoding

Generally, NR should provide gNB the flexibility to configure the set of aggregation levels. The aggregation levels {1, 2, 4, 8} is agreed. Moreover, even larger aggregation levels can be considered for URLLC (e.g., 16 and/or 32) or for increasing PDCCH coverage. As discussed in [8], at least aggregation level 16 should be supported in NR.

Proposal 7: *Aggregation level of 16 should be supported in NR.*

Although both aggregation levels and the number of PDCCH candidates per aggregation level are configurable, the maximum number of blind decodings still should be defined as one of UE capability. The maximum number of blind decodings can refer to those of LTE (i.e. 44 or 60), and preferably not be exceeded in NR. The maximum number of blind decoding can be seen as a UE-specific capability. After the capability is reported, gNB will configure the number of blind decodings per aggregation level and per DCI format size accordingly.

Proposal 8*: Confirm the working assumption that the exact value of maximum blind decodes X per slot per carrier should not exceed 44 when only slot-based scheduling is configured for UE.*

In addition, as discussed in [9], when UE is configured with both non-slot-based scheduling and slot-based scheduling, one alternative is that the maximum number of PDCCH blind decodes per slot per carrier is still equal to X. Another alternative is that the maximum number of PDCCH blind decodes per slot per carrier is equal to Z, where Z=X+Y, Y is the maximum number of PDCCH blind decodes per slot per carrier when UE is only configured for non-slot-based scheduling.

Proposal 9*: When UE is configured with both non-slot-based scheduling and slot-based scheduling, the maximum number of PDCCH blind decodes per slot per carrier for the given UE is down-selected from the following alternatives:*

- *Alt 1: equal to X*

- *Alt 2: equal to Z, where Z=X+Y, Y is the maximum number of PDCCH blind decodes per slot per carrier when UE is only configured for non-slot-based scheduling*
  - *Alt 2-1: Z does not exceed 44*
  - *Alt 2-2: Z slightly exceeds 44, e.g., 44+14*

Although both aggregation levels and the number of PDCCH candidates per aggregation level are configurable, UE PDCCH blind decoding capability still should be defined for a UE monitoring PDCCH(s). This can be considered as a benchmark for gNB configuring aggregation levels and/or the number of PDCCH candidates for each aggregation level. Moreover, such capability can be reported by a UE if needed, e.g., for energy saving. Otherwise, when in scenarios of multi-BWP, multi-TRP, multi-carrier, the configured number of blind decoding may exceed the capability of UE. In order to avoid this case, gNB should know the capability of UE, then gNB will configure the number of blind decodings according to the reported UE capability. In another word, the capability can be expressed as a default number of PDCCH candidates for each aggregation level that a UE monitors for scheduling assignment/grant of PDSCH(s)/PUSCH(s).

Proposal 10: *Define a default number of PDCCH candidates for each aggregation level that a UE monitors for scheduling assignment/grant of PDSCH(s)/PUSCH(s).*

In the case of multiple CORESETs for scheduling of the same PDSCH/PUSCH are monitored by a UE, candidate splitting is needed between/among different CORESETs. In LTE EPDCCH, the splitting is defined in the specification, e.g. by using a tabulated split for each possible PDCCH allocation. However, such tabulated split may not be suitable for NR PDCCH due to the flexibility of CORESET configuration including time duration, REG bundle size, transmission type, QCL, etc. As a result, it is proposed that the number of PDCCH candidates can be explicitly indicated.

Proposal 11: *The number of PDCCH candidates per aggregation level should be explicitly configured at least for the case with $K \geq 2$ CORESETs.*

To achieve the robust transmission for one PDCCH (e.g. one specific DCI format), UE can be configured to monitor one PDCCH from more than one search space types (e.g. common/UE-specific search space) which are associated with specific configurations (e.g. CORESET, QCL, DMRS, etc).

Proposal 12: *A UE can be configured to monitor one PDCCH from one or multiple search space types (e.g., common or UE-specific).*

2.3 Multi-beam operation

After RRC connection establishment/re-establishment, UE can receive the CORESET configuration via dedicated RRC signaling. Furthermore, it is agreed that multi-beam related information can be indicated by *RRC only or RRC + MAC CE signaling*. Information on multi-beam operation for PDCCH can be also involved into the CORESET configuration. Since different beams may result in different channel conditions such as average gain, average delay, delay spread, or Doppler frequency shift due to different beams from different panels/TRPS or different beam direction even at same TRP, joint Quasi-Co-Location (QCL) relation between DMRS for PDCCH and CSI RSs for beams can be configured to help corresponding PDCCH candidate decoding. In order to support forward capability, multiple QCL assumptions within a CORESET can be configured to a UE. A typical example can be shown in Figure 6. For specific aggregation level, one or several PDCCH candidate(s) will correspond to one beam and hence the DMRSs within the REG bundle(s) used by the PDCCH candidate(s) will be QCLed with the CSI RS configured for the same beam.

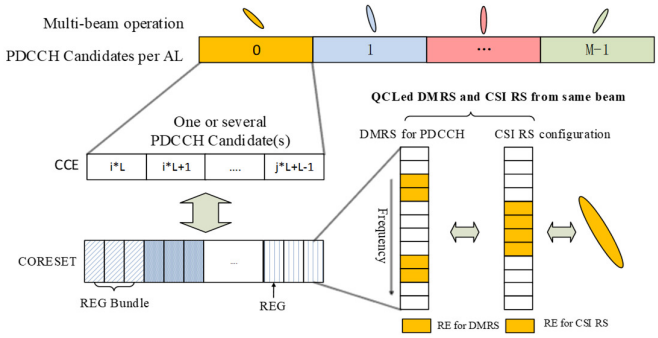

Figure 6 QCL between DMRS for PDCCH and CSI RS for multi-beam operation.

It should be noted that QCL relation is not necessary to be configured for each AL within CORESET, due to nested search space. Once QCL relation configured for PDCCH candidates of higher AL, the QCL assumption for each candidates of lower ALs can be derived from its nested relationship with the higher AL. An example can be shown in Figure 7, where QCL relation for PDCCH candidates at AL 8 was configured and hence that for AL 1/2/4 can be derived, based on the nested property.

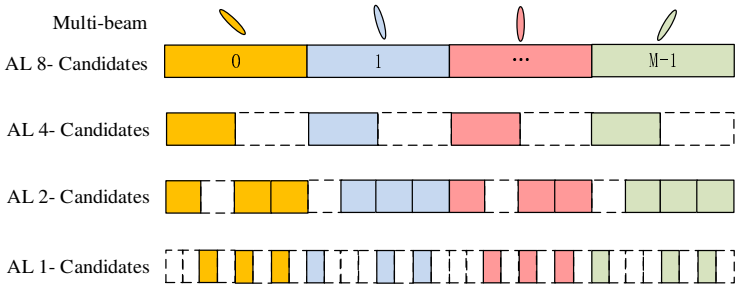

Figure 7 QCL assumption derived from nested search space

Based on the above discussion, we have the following proposals

Proposal 13: *QCL relation will be configured only for PDCCH candidates of the highest aggregation level in an aggregation level group for nested search space structure. QCL relation for candidates of lower aggregation level will be implicitly derived.*

2.4 PDCCH configurability per CORESET

NR supports multiple PDCCHs each scheduling a respective PDSCH where each PDCCH is transmitted from a separate TRP. In RAN1 #90 meeting, it was also agreed that *the maximum supported number of NR-PDCCHs corresponding to scheduled NR-PDSCHs that a UE can be expected to receive in a single slot is 2 on a per component carrier basis in case of one bandwidth part for the component carrier*. One example of a use-case where a UE receives multiple NR-PDCCHs in a given slot is with NC-JT, as described in our companion contribution [10], where different TRPs independently schedule a transmission towards the same UE in the same slot and each NR-PDCCH is transmitted in its respective CORESET. Other configurations where a UE is configured to receive multiple NR-PDCCHs in a given slot in the same CORESET are also possible. This makes it clear that there is a need for the UE to know the association between PDCCHs and CORESETs. Thus, it is proposed that NR should support the configurability of the number of PDCCHs in each given CORESET. Moreover, the number of PDCCHs should be signaled to the UE implicitly. This is beneficial for not only scheduling flexibility but also reducing of UE blind decoding attempts.

Proposal 14: *For a given UE, the association between a CORESET and a NR-PDCCH can be configured by RRC signaling.*

As proposed in our companion's contribution [11][1], there are multiple MAC entities in the network involved in transmission to a multi-connectivity UE at least for non-ideal backhaul. To simplify the UE behavior, a correspondence between the number of PDCCHs and the number of MAC entities observable

by the UE where each MAC has its own set of HARQ processes corresponding to each connection is required.

To guarantee that a UE is able to route a PDCCH to the right MAC entity for the control and data receptions, association between PDCCH and MAC entity should be explicitly configured. By extension, if for each MAC entity there is a respective HARQ entity, then the association between PDCCH and MAC entity can also be viewed as being between PDCCH and HARQ entity. In order to simplify the standardization effort, the association between PDCCH and MAC entity (by extension HARQ entity) can be done at the CORESET level. When multiple CORESETs carrying multiple PDCCHs are configured to a UE, the CORESETs can correspond to one or multiple MAC entities (by extension HARQ entities) depending on the configured association of CORESET and MAC entity (by extension HARQ entity) for each CORESET. Moreover, time and frequency resources of CORESETs from TRPs can be semi-statically coordinated between TRPs in CORESET level. Therefore, the association between CORESET and HARQ entity can be configured to a UE with the CORESET configuration, i.e. using RRC signaling.

Proposal 15: *Association between CORESET and HARQ entity should be configured by RRC signaling.*

3 Conclusions

Our observations and proposals in this contribution are summarized as follows.

Observation 1: *Sparsely nested structure of search space has lower blocking probability compared with continuously nested structure of search spaces.*

Proposal 1: *The candidate configurations provided in Table 1 can be the starting point for configuration of the CORESET for scheduling RMSI.*

Proposal 2: *RMSI can be used to indicate a CORESET for other system information, paging, etc.*

Proposal 3: *Default monitoring periodicities should be predefined for monitoring PDCCH.*

Proposal 4*: Confirm the working assumption: Re-use NR DL RA type 0 basis in units of 6 RBs, where no restriction on the maximum number of segments for a given CORESET.*

Proposal 5*: Additional CORESET(s) with common search space(s) can be configured by UE-specific RRC signaling.*

Proposal 6: *When CCEs corresponding to a search space with higher aggregation level contains CCEs corresponding to a search space with lower aggregation level*

- *The PDCCH candidates with the highest aggregation level should be located non-contiguously.*
- *The PDCCH candidates with lower aggregation level should be located non-contiguously and non-uniformly within the set of CCEs corresponding to the PDCCH candidates at the highest aggregation level.*
- *The CCEs corresponding to the search space with lower aggregation level is associated with the UE's C-RNTI/a configurable UE-specific ID.*

Proposal 7: *Aggregation level of 16 should be supported in NR.*

Proposal 8*: Confirm the working assumption that the exact value of maximum blind decodes X per slot per carrier should not exceed 44 when only slot-based scheduling is configured for UE.*

Proposal 9*: When UE is configured with both non-slot-based scheduling and slot-based scheduling, the maximum number of PDCCH blind decodes per slot per carrier for the given UE is down-selected from the following alternatives:*

- *Alt 1: equal to X*
- *Alt 2: equal to Z, where Z=X+Y, Y is the maximum number of PDCCH blind decodes per slot per carrier when UE is only configured for non-slot-based scheduling*
  - *Alt 2-1: Z does not exceed 44*
  - *Alt 2-2: Z slightly exceeds 44, e.g., 44+14*

Proposal 10: *Define a default number of PDCCH candidates for each aggregation level that a UE monitors for scheduling assignment/grant of PDSCH(s)/PUSCH(s).*

Proposal 11: *The number of PDCCH candidates per aggregation level should be explicitly configured at least for the case with $K \geq 2$ CORESETs.*

Proposal 12: *A UE can be configured to monitor one PDCCH from one or multiple search space types (e.g., common or UE-specific).*

Proposal 13: *QCL relation will be configured only for PDCCH candidates of the highest aggregation level in an aggregation level group for nested search space structure. QCL relation for candidates of lower aggregation level will be implicitly derived.*

Proposal 14: *For a given UE, the association between a CORESET and a NR-PDCCH can be configured by RRC signaling.*

Proposal 15: *Association between CORESET and HARQ entity should be configured by RRC signaling.*

4 References

[1] 3GPP, "Draft report of 3GPP TSG RAN WG1 #89 v0.2.0", Hangzhou, China, 15-19 May, 2017.

[2] 3GPP, "Draft Report of 3GPP TSG RAN WG1 #AH_NR2 v0.1.0", Qingdao, China, 27-30 June, 2017.

[3] 3GPP, "Draft report of 3GPP TSG RAN WG1 #90 v0.1.0", Prague, Czech Republic, 21-25 August, 2017.

[4] 3GPP "Draft report of 3GPP TSG RAN WG1 #AH_NR3 v0.1.0", Nagoya, Japan, 18-21 September, 2017.

[5] R1-1717050, "RMSI Delivery", Huawei, HiSilicon, Prague, Czech Republic, 9-13 October, 2017.

[6] R1-1717064, "DCI contents and formats in NR", Huawei, HiSilicon, Prague, Czech Republic, 9-13 October, 2017.

[7] R1-1706945, "Nested search space design", Huawei, HiSilicon, Hangzhou, China, 15-19 May, 2017.

[8] R1-1717086, "PDCCH reliability for URLLC", Huawei, HiSilicon, Prague, Czech Republic, 9-13 October, 2017.

[9] R1-1717085, "Summary on open issues for non-slot-based transmission", Huawei, HiSilicon, Prague, Czech Republic, 9-13 October, 2017.

[10] R1-1715462, "Enabling multiple NR-PDCCH for multiple TRP transmission", Huawei, HiSilicon, Nagoya, Japan, 18-21 September, 2017.

[11] R2-1708884, "Potential Advantages of multi-connectivity with multiple MAC entities within an NR cell", Huawei, HiSilicon, Berlin, Germany, 21-25 August, 2017.

Appendix A

The following agreements have been achieved in previous meetings on CORESET configuration and search space design:

In RAN1 meeting #89 [1],

- *Following contents are carried in NR-MIB*
  - *RMSI scheduling information: [x] bits*
    - *CORESET(s) information: [x] bits*
      - *Simplified information of CORESET(s) compared to CORESET(s) information for UE-specific configuration is considered*
      - *E.g., Time/frequency resource configuration of CORESET(s)*

In RAN1 #Ad-Hoc 2 meeting [2],

- *For a CORESET which is configured by UE-specific higher-layer signaling, at least following are configured.*

    - *Frequency-domain resources, which may or may not be contiguous*
        - *Each contiguous part of a CORESET is equal to or more than the size of REG-bundle in frequency*
            - *FFS: exact size and number of contiguous parts for a CORESET*
    - *Starting OFDM symbol*
    - *Time duration*
    - *REG bundle size if the configuration is explicit*
    - *Transmission type (i.e., interleaved or non-interleaved)*
    - *More parameters may be added if agreed*

- *For PDCCH blind decoding, at least for the non-initial access, at least the following can be configured:*
    - *Number of PDCCH candidates per CCE aggregation level, per DCI format size that the UE monitors*
    - *Set of aggregation levels*
    - *FFS explicit or implicit configuration*
    - *Set of DCI format sizes*
    - *FFS explicit or implicit configuration*
    - *FFS: per CORESET not used for initial access or search space*
    - *FFS: Signaling details*
    - *Note that the number of candidates can be zero*

- *UE blind decoding capability is known by NW*
    - *FFS: How the capability is derived*

In RAN1 meeting #90 [3],

Agreements:

- *At least for initial access, RAR is carried in NR-PDSCH scheduled by NR-PDCCH in CORESET configured in RACH configuration*
    - *Note: CORESET configured in RACH configuration can be same or different from CORESET configured in NR-PBCH*

- *In RRC CONNECTED mode,*
    - *RRC only or RRC+ MAC CE signaling is used to indicate QCL relation (at least w.r.t spatial RX parameters) between DMRS port(s) of UE-specific PDCCH and either SS Block or P/SP CSI-RS resource(s)*

- *A PDCCH search space at an aggregation level in a CORESET is defined by a set of PDCCH candidates*
- *For the search space at the highest aggregation level in the CORESET, the CCEs corresponding to a PDCCH candidate are derived as following*
    - *The first CCE index of a PDCCH candidate is identified by using at least some of the followings*
        - *(1) UE-ID, (2) candidate number, (3) total number of CCEs for the PDCCH candidate, (4) total number of CCEs in the CORESET, and (5) randomization factor*
    - *The other CCE indexes of the PDCCH candidate are consecutive from the first CCE index*
- *Searching space design for the lower aggregation level can be discussed separately*

- *The maximum supported number of NR-PDCCHs corresponding to scheduled NR-PDSCHs that a UE can be expected to receive in a single slot is 2 on a per component carrier basis in case of one bandwidth part for the component carrier*
    - *FFS the case of multiple BWPs for the component carrier if supported*
    - *(Working assumption) In this case, at most a total of 2 CWs over the scheduled NR-PDSCHs*
- *For multiple NR-PDCCH reception for scheduled NR-PDSCHs:*
    - *FFS whether or not there is any impact on # of HARQ processes and/or soft buffer management*

- *FFS the mapping between PUCCH conveying ACK/NACK signaling and PDSCH*
- *Note: this topic is more suitable for discussion under scheduling/HARQ session*

Working assumptions:

- *In the case when only CORESET(s) for slot-based scheduling is configured for UE, the maximum number of PDCCH blind decodes per slot per carrier is X*
  - *The value of X does not exceed 44*
  - *FFS the exact value of X*
  - *FFS for multiple active BWP, multiple TRP, multiple carriers, multi beams*
    - *44 + Kn, K<44*
  - *FFS for non-slot based scheduling*
  - *FFS numerology specific X*

In RAN1 meeting NR-AH#3 [4],

Working assumption:

- *Re-use NR DL RA Type 0 basis in units of 6 RBs, where no restriction on the maximum number of segments for a given CORESET.*

Agreements:

- *The QCL configuration for PDCCH contains the information which provides a reference to a TCI state*
  - *Alt 1: The QCL configuration/indication is on a per CORESET basis*
    - *The UE applies the QCL assumption on the associated CORESET monitoring occasions. All search space(s) within the CORESET utilize the same QCL.*
  - *Alt 2: The QCL configuration/indication is on a per search space basis*
    - *The UE applies the QCL assumption on an associated search space. This could mean that in the case where there are multiple search spaces within a CORESET, the UE may be configured with different QCL assumptions for different search spaces.*
  - *Note: The indication of QCL configuration is done by RRC or RRC + MAC CE (FFS: by DCI)*

Note: The above options are provided as input to the control channel agenda item discussion

Appendix B

Blocking probability comparison

In order to compare the blocking probability of the designs discussed in section 2.1 for nested search space, evaluation is performed and discussed in this section. In the evaluation, the total number of CCEs is assumed to be 64 or 128. The number of PDCCH candidates of search spaces keeps the same as UE-specific search spaces in LTE, $M^{(L)} = \{6,6,2,2\}$ for aggregation level $L = \{1,2,4,8\}$. The probability for aggregation selection is assumed to be {0.1, 0.6, 0.2, 0.1}. Since the scheduling order of PDCCH is mainly determined by information of the data transmission (e.g. proportional-fairness scheduler), the scheduling order of those aggregation levels is random. The average blocking probabilities of three search space structures are shown in Fig. 8.

In Fig. 8, two search space structures are simulated, one is continuously nested search space as shown in Figure 3, the other is sparsely nested. It shows that, as the average number of UEs increases, the blocking probability gradually increases. When the continuously nested structure of search space is employed, the blocking probability increases compared with LTE benchmark, since a high blocking region always exists in the continuously nested search space structure. On the other hand, when sparsely nested structure of search space is employed, the average blocking probability is reduced. Compared with the continuously nested structure of search space, there is almost 2% reduction of the blocking probability. Moreover, the blocking probability of sparsely nested structure of search space also slightly lower than LTE benchmark.

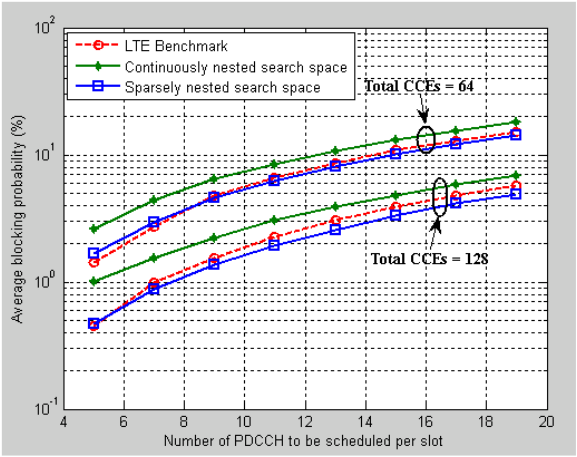

Fig. 8. The average blocking probabilities of different search space structures.