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Title: Summary of key aspects for search space
Agenda Item: 7.3.1.2
Document for: Discussion and Decision

1. Introduction

Following aspects are the remaining key issues on PDCCH structure to finalize as soon as possible.

- **Key issue 1: Details on CORESET configuration**
 - For a CORESET for PDCCH scheduling UE-specific data,
 - ✧ Remaining details on frequency-domain allocation
 - ✧ Starting OFDM symbol of the CORESET
- **Key issue 2: Details on search space configuration (if any)**
 - Whether/what parameters are needed to identify a search space within a given CORESET for PDCCH scheduling UE-specific data
 - Hashing function for a given search space
- **Key issue 3: PDCCH blind decoding**
 - Whether the UE reports PDCCH blind decoding capability to the NW
 - How to distribute PDCCH blind decodes over multiple CORESETs/search spaces for a given PDCCH monitoring occasion
- **Key issue 4: QCL configuration**
 - QCL for PDCCH candidates

Note that ASN.1 will be fixed on December RAN plenary meeting. Therefore, RAN1 should target fixing all necessary RRC parameters at the end of RAN1#90bis meeting.

2. Key issue 1: Details on CORESET configuration

RRC parameters for CORESET configuration are listed in [1]. However, not all the parameters are clear yet. In [2], following questions were raised:

- Whether the frequency-domain allocation of a CORESET is based on BWP or some other?
- What are the starting OFDM symbol for a CORESET?

Those issues need to be resolved to finalize the RRS parameter list.

2-1 Frequency-domain allocation of a CORESET

On the frequency-domain allocation of a CORESET for PDCCH scheduling UE-specific data, there is an association between DL BWP and PDCCH. So, it is natural to consider that the frequency-domain allocation of a CORESET for PDCCH scheduling UE-specific data can be based on the associated DL BWP. For a CORESET for PDCCH scheduling RMSI, different way of frequency-domain allocation is necessary. Besides, most companies are OK to confirm the WA. So, here the proposal is following.

Proposal 1:

- Confirm the WA ‘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’ with the following clarifications:
 - This is for the CORESET configured by UE-specific RRC signaling
 - This is based on the DL BWP associated with the CORESET for PDCCH scheduling UE-specific data.
- For the CORESET configured by PBCH, number of bits and configurable parameters should be discussed in initial access session.

Other views or suggestion on the above?

Company	View
vivo	OK with the proposal.

2-2 Time-domain allocation of a CORESET

There is a working assumption ‘for slot-based scheduling, the first DMRS position either on 3rd symbol or 4th symbol is configured by [PBCH], where the maximum time duration of a CORESET is 2 symbols if the first DMRS position of a PDSCH with slot-based scheduling is on 3rd symbol, and is 3 symbols otherwise’. Since there is no objection for this, we should confirm the working assumption as agreement (with removing the blanket on [PBCH]). For mini-slot-based scheduling, Intel suggested that the maximum time duration of a CORESET of 2 symbols is sufficient, which seems reasonable proposal and should be agreeable.

On the starting OFDM symbol of a CORESET, for slot-based scheduling, it is sufficient to configure a CORESET at the beginning of a slot, with some flexibility in time to realize TDM between cORESETs. For non-slot-based scheduling, it is useful to enable CORESET starting at any OFDM symbol, where the need of some restrictions on particular cases (e.g., whether a CORESET can span a slot boundary) should be FFS. Therefore, the proposal is following.

Proposal 2:

- For a slot-based scheduling;
 - Conform the following working assumption with replacing [PBCH] by PBCH.
 - ✧ The first DMRS position either on 3rd symbol or 4th symbol is configured by [PBCH]
 - Maximum time duration of a CORESET is 2 symbols if the first DMRS position of a PDSCH with slot-based scheduling is on 3rd symbol, and is 3rd symbol otherwise.
 - The starting OFDM symbol of a CORESET can be #0, #1, or #2 symbol in a slot.
 - ✧ However, the ending OFDM symbol of a CORESET is not later than #2 symbol in a slot.
- For a mini-slot-based scheduling,
 - The starting OFDM symbol of a CORESET can be any symbol in a slot.
 - ✧ Further restrictions are FFS.

Other views or suggestion on the above?

Company	View
vivo	OK with the proposal

3. Key issue 2: Details on search space configuration (if any)

At the RAN1 NR Ad-hoc#3 meeting, following agreement was achieved:

Agreements:

- In a given CORESET
 - ✧ Alt 1: different DCI formats
 - ✧ Alt 2: different search spaces
 can have different monitoring periodicities.
 - ✧ FFS which one

3-1 Whether different DCI formats or search spaces can have different monitoring periodicities

One example of the motivations of this agreement is to enable UE to monitor CSS on one periodicity and USS on another periodicity, where both of them still belong to the same CORESET. Therefore, at least Alt.2 should be available. Assuming different search spaces have different monitoring periodicities, different DCI formats can have different monitoring periodicities by mapping different DCI formats to different search spaces. Therefore, following is proposed:

Proposal 3:

- *In a given CORESET, UE-common search space and UE-specific search space can have different periodicities.*

Other views or suggestion on the above?

Company	View
vivo	OK with the proposal
ZTE	We think this fixed of previous agreement is needed. We should clarify the different periodicity are applied for each type of search spaces. To make the definition more clear, I would say different types of search spaces (CSSs or UE-specific SSs). In our difination, each Aggregation levels can have one search spaces. CSS type can have multiple SSs. UE-specific SS type can also have another set of SSs. Those definition was also used in LTE specifaication (36.213). On top of each SS types, we can further discuss if different DCI format will have different monitoring periodicity etc.

3-2 Configurations to identify search spaces for a DCI format/size

In order to identify exact PDCCH candidates for a given CORESET, UE needs to know following factors:

- DCI format/size
- Aggregation level(s) for the DCI format/size
- Monitoring occasion for the given DCI format/size with the given aggregation level
- Number of PDCCH candidates for the given DCI format/size with the given aggregation level at the given monitoring occation

For PDCCH scheduling UE-specific data, DCI format/size to monitor is derived from various RRC configurations. Then, possible necessary parameters to execute the PDCCH candiates monitoring for the DCI format/size are 2nd, 3rd, and 4th bullets in the above. So far, following agreements were achieved:

Agreements:

- 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: Signalling details
- Note that the number of candidates can be zero
- UE blind decoding capability is known by NW
 - FFS: How the capability is derived

It is not so far obvious that how much flexibility for the configuration of PDCCH blind decoding is required. Many companies suggest to enable configuring the number of blind decoding attempts per aggregation level and per each DCI format size by higher layer signaling. However, full flexibility would not be necessary. Our understanding is following:

- It is beneficial to enable configuring how many DCI formats/sizes the UE monitors, for a given monitoring occasion for a given CORESET. However, the number {1 or 2} is sufficient for this configuration.
- It is beneficial to enable configuring a set of aggregation levels the UE monitors, for a given monitoring occasion for a given CORESET. However, it is not necessary to make any combination is selectable. Define two sets of aggregation levels for a given monitoring occasion for a given CORESET would be a possible way.
- It is beneficial to enable configuring the number of PDCCH candidates the UE monitors, for a given aggregation level for a given monitoring occasion for a given CORESET. However, it is not necessary to make any number is selectable. Define a scaling value, and apply it to all the aggregation levels for a given monitoring occasion for a given CORESET would be a possible way.

From the above discussion, following are proposed:

Proposal 4:

- *For UE-specific search space, UE monitors PDCCH candidates with the following details:*
 - *UE is configured with PDCCH monitoring periodicity and offset to derive a PDCCH monitoring occasion in the given CORESET.*
 - ✧ *The monitoring occasion derived from the periodicity/offset is a subset of the CORESET occasion.*
 - *For the given PDCCH monitoring occasion in the given CORESET, the UE is configured to monitor 1 or 2 DCI formats/sizes.*
 - *For the given PDCCH monitoring occasion of the DCI format size(s), the UE is configured with the set of aggregation level(s) to monitor, set A or set B.*
 - ✧ *Exact sets of aggregation levels in set A and in set B are FFS.*
 - *For the given PDCCH monitoring occasion of the DCI format(s)/size(s) and the given set of aggregation level(s), the number of PDCCH candidates is determined by $M^{(L)} = \text{round}(a \times M_{full}^{(L)})$, where the value of a is configured by higher-layer signaling and $M_{full}^{(L)}$ is the maximum number of PDCCH candidates with the aggregation level L .*
 - ✧ *$M_{full}^{(L)}$ is to be specified.*
 - ✧ *For a , four values are specified, and higher-layer signaling configures one of the four values.*

Other views or suggestion on the above?

Company	View
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vivo	How the $M_{full}^{(L)}$ is defined should be further discussed. We think when some aggregation level(s) are disabled, or the number of candidates for some aggregation level(s) are reduced, it should be possible to configure UE to do more blind decodes on other aggregation levels, as long as the maximum blind decoding capability per slot is not exceeded. For example, in the baseline case the UE can be configured to monitor AL set [1,2,4,8] with [6,6,2,2,] candidates, in another configuration, if AL [4,8] is turned off, more candidates should be allowed for AL [1,2], which means [8,8] candidates can be configured for AL[1,2], respectively.
ZTE	We suggest to use set of predefined table to list the number of candidates per AL

3-3 Hashing function

As for hashing function, following proposals are found:

- R1-1717062 (Huawei)
 - $L_{\max} \left\{ (Y_k + f(m^H)) \bmod \left\lfloor \frac{N_{CCE}}{L_{\max}} \right\rfloor \right\} + i$ for the highest AL and $L \{W_k + g(m)\} \bmod \left\lfloor \frac{L_{\max}}{L} \right\rfloor + l_{m^H} + i$ for the other ALs, where $f(m^H)$ is a function where PDCCH candidates are distributed uniformly or non-uniformly within the CORESET, and $g(m)$ is a function where PDCCH candidates are distributed non-uniformly within the set of CCEs for the PDCCH candidate with the highest AL
- R1-1718628 (Ericsson)
 - $L \{ (Y_k + m') \bmod \lfloor N_{CCE,k} / L \rfloor \} + i$
- R1-1718204 (DOCOMO)
 - $L \left\{ Y_k + \left\lfloor \frac{m \cdot N_{CCE}}{L \cdot M^L} \right\rfloor \bmod \left\lfloor \frac{N_{CCE}}{L} \right\rfloor \right\} + i$ for the highest AL and $l \left\{ Y_k + \left\lfloor \frac{m \cdot (L \cdot M^L)}{l \cdot M^l} \right\rfloor \bmod \left\lfloor \frac{(L \cdot M^L)}{l} \right\rfloor \right\} + i$ for the other ALs, where L is the highest AL and l is the other AL.
- R1-1717379 (Intel)
 - $L \left\{ (Y_k + \pi_k(m) + b) \bmod \left\lfloor \frac{N_{CCE,k}^L}{L} \right\rfloor \right\} + i$, where $N_{CCE,k}^L$ is the total number of CCEs in the CORESET for the highest AL, and $N_{CCE,k}^L$ is the $L^{\text{Highest}} \times M^{\text{Highest}}$ for the other AL. $\pi_k(\cdot)$ is a pseudo-randomly permuted sequence and b is for CA, e.g., carrier indicator field as in LTE.
- R1-1717511 (ZTE)
 - within the set of CCEs for the PDCCH candidate with the highest AL, each candidate pattern per AL can be determined through a combinatorial index r which is defined as:
$$r = \sum_{i=0}^{M-1} \binom{N-s_i}{M-i}, \text{ where the set } \{s_i\}_{i=0}^{M-1}, (1 \leq s_i \leq N, s_i < s_{i+1}) \text{ contains the } M \text{ sorted candidate positions and}$$

$$\binom{x}{y} = \begin{cases} \binom{x}{y} & x \geq y \\ 0 & x < y \end{cases} \text{ is the extended binomial coefficient, resulting in unique label } r \in \left\{ 0, \dots, \binom{N}{M} - 1 \right\}.$$
 - r value is randomly generated.

Proposal 5:

- *Hash function is selected from the proposals in the contribution.*

Other views or suggestion on the above?

Company	View

4. Key issue 3: PDCCH blind decoding

In the following agreements and working assumptions, whether to inform the possible number of PDCCH blind decodes by UE capability signaling and how to determine the maximum number of PDCCH blind decodes are the remaining issues.

Agreements:

- 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: Signalling details
 - Note that the number of candidates can be zero
- UE blind decoding capability is known by NW
 - FFS: How the capability is derived

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
 - FFS for non-slot based scheduling
 - FFS numerology specific X

4-1 Whether to inform UE blind decoding capability to the NW by the capability signalling

Some companies (vivo, Samsung, LGE) prefers to support explicit UE capability signaling for the number of blind decodes. So far, the need of explicit UE capability signaling is not clear, while the introduction of the explicit UE capability signaling for PDCCH blind decoding would complicate the scheduler. Our suggestion is to derive the maximum number of PDCCH blind decodes per slot per carrier by other parameters, e.g., number of CCs. But it seems many companies prefer to define the UE capability signaling. Please let me know your view.

Proposal 6:

- *Explicit UE capability signaling for the maximum number of PDCCH blind decodes per slot per carrier is not introduced.*

Other views or suggestion on the above?

Company	View
vivo	As discussed in our contribution R1-1717484, we see the drawbacks of implicit linkage of blind decoding capability with other capabilities, e.g. CA or mini-slot Firstly, if the blind decoding capability is implicitly linked to the CA parameters, it imposes the blind decoding capability to be linearly dependent to the number of supported carriers, which is not desirable from the UE implementation perspective, especially when the aggregated carrier is large. Secondly, it may not fully exploit the blind decoding capability of UE in some scenarios. For example, if a UE capable of mini-slot scheduling accesses to a network that mini-slot is not used, although the UE has higher processing capability, the blind decoding capability cannot be fully utilized to enable better performance, e.g. increase scheduling opportunities and reduced blocking. Therefore, an explicit UE capability signaling for PDCCH blind decoding capability is more future-proof and desirable.

4-2 Distribution of the number of PDCCH blind decodes among CORESETs/search spaces for a slot of a carrier

We propose to confirm the WA.

Proposal 7:

- *Confirm the WA '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 where $X \leq 44$ '.*

Other views or suggestion on the above?

Company	View
vivo	Confirm the main bullet of the WA is fine. In Nagoya, there was offline discussion about numerology specific X value, which seems to be agreeable as well. Therefore we would like to agree on "X is numerology specific" together with the WA.

5. Key issue 4: QCL configuration

So far, following agreements have been made:

Agreement: 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
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Our suggestion is Alt.1.

Proposal 8:

- *Select 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.*

Other views or suggestion on the above?

Company	View
Vivo	Support the proposal.
ZTE	I may not be the QCL expert. However, I assume here we only use the same QCL assumption for UE-specific SS type. For UE-specific SSs, they can assume same QCL in a CORESET.

6. Appendix A: Current RRC parameters related to PDCCH

Parameter name in text	Description	Value range	Default value	Comment
DL-BWP-mu	• The subcarrier spacing of DL BWP configuration is applied to at least PDCCH, PDSCH & corresponding DMRS. Table 4.1-2 in 38.211	0,1, 2, 3, 4 or 5		
UL-BWP-mu	• The subcarrier spacing of UL BWP configuration is applied to at least PUCCH, PUSCH & corresponding DMRS.	0,1, 2, 3, 4 or 5		
DL-BWP-cp	Configure the CP for the bandwidth part. Support CPs are normal CP (for all numerologies and slot formats), extended CP for 60 kHz numerology	Normal CP, Extended CP	Normal CP	
UL-BWP-cp	Configure the CP for the bandwidth part. Support CPs are normal CP (for all numerologies and slot formats), extended CP for 60 kHz numerology	Normal CP, Extended CP	Normal CP	
DL-BWP-BW	The applicable bandwidth for the configured DL BWP			
UL-BWP-BW	The applicable bandwidth for the configured UL BWP			
DL-BWP-loc	Frequency location of the DL-BWP			
UL-BWP-loc	Frequency location of the UL-BWP			
CORESET-freq-dom	Frequency domain resources for the CORESET			included in CORESET • 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.
CORESET-start-symb	Starting OFDM symbol for the CORESET			included in CORESET
CORESET-time-duration	Contigouse time duraation of the CORESET	1,2,3	NA	included in CORESET
CORESET-REG-bundle-size	38.211 clause 7.3.2.2	2, 6		included in CORESET
CORESET-CCE-REG-mapping-type	CCE-REG mapping type for the CORESET, it is either interleaved or non-interleaved	interleaved, non-interleaved		included in CORESET
CORESET-precoder-granularity	For a CORESET, precoder granularity in frequency domain	reg-bundle-size, nbr-contiguous-RBs-within-CORESET		included in CORESET
Preemp-DL	Turn on monitoring of DL preemption DCI	ON, OFF	OFF	
INT-RNTI	RNTI used for indication pre-emption in DL. Also connected to monitoring of a Type2-PDCCH common search space.	RNTI value		
int_symbols_unit	Size of each block of OFDM symbols indicated with punctured transmission			
UL-DL-configuration	RRC configured UL-DL configuration of slots for NR			
Num-PDCCH-cand	- 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			
Group-common-PDCCH-SFI	Monitoring of a group common PDCCH for at least SFI	ON, OFF	OFF	
SFI-CORESET		CORESET	NA	
DL-preemption-CORESET		CORESET	NA	
CORESET		See parameters included in CORESET	NA	
cif-Presence	Indicate CIF presence or not in DCI follwoning LTE design	TRUE, FALSE	FALSE	

7. Appendix B: Agreements regarding PDCCH

RAN1#86b

Agreements: NR should support

- UE/PDCCH-specific DM-RS for PDCCH reception. At least for beamforming, UE may assume same precoding operation for PDCCH and associated DM-RS for PDCCH.
 - FFS: DM-RS is PDCCH-specific and/or UE-specific
- Shared/Common RS for PDCCH reception
 - Whether this sharing will be transparent to UE is FFS
 - FFS: Whether UE may assume the same precoding operation between RS and PDCCH
- FFS: QCL between antenna ports for PDCCH demodulation
- Tx diversity supported. Which scheme/how FFS

Agreements: For the frequency-domain aspects:

- A UE monitors for downlink control information in one or more “control subband”
 - This does not preclude that UE may receive additional control information elsewhere within or outside the control subband in the same or different OFDM symbol(s)
 - FFS: One DCI message is transmitted within one control subband.
- A “control subband” is smaller than or equal to the carrier bandwidth (up to a certain limit)
- FFS if a “control subband” is non-contiguous and/or contiguous in the frequency domain.
- A “control subband” consists of an integer number of RBs/PRBs in the frequency domain
- FFS: multiplexing of multiple control channels in a subband

Agreements:

- From gNB perspective, DL control signalling can be located at the first OFDM symbol(s) in a slot and/or mini-slot
- FFS: From gNB perspective, DL control signalling can be located over the slot and/or mini-slot

Agreement:

- NR supports at least same-slot and cross-slot scheduling for DL.
 - Note: it is already agreed that NR supports same-slot and cross-slot scheduling for UL.

Agreements:

- NR should support both data and control with the same numerology
- Study impact and benefits of allowing the transmission of DL control information and data transmission to a UE within the same slot interval using different numerologies in TDM or FDM manner
 - Above may apply both slot and mini-slot
- Study impact and benefits of allowing the transmission of uplink control information and data transmission from a UE within the same slot interval using different numerologies in TDM or FDM manner
 - Above may apply both slot and mini-slot
- Followings applies both DL and UL
 - The associated DM-RS for data/control transmission still uses the same numerology as the data/control transmission
 - FFS: Control channel performance under different numerologies, Overhead saving, Control channel capacity; Quantify timeline saving, UE complexity

Agreements:

- NR should support at least the following.
 - In frequency-domain, a PRB (or a multiple of PRBs) is the resource unit size (may or may not including DM-RS) for control channel
 - This is at least for the case where the DL control region consists of one or a few OFDM symbol(s) of a slot or a mini-slot

- FFS: whether a PRB or a multiple PRBs is the resource unit size
 - FFS: If multiple PRBs is the resource unit size, the multiple PRBs are contiguous
- FFS: whether the resource unit size for a DL control channel is called as NR-REG or not

Agreements:

- NR should support at least the following
 - A DL control channel can be mapped on one or more NR-CCEs
 - This is at least for the case where the DL control region consists of one or a few OFDM symbol(s) of a slot or a mini-slot
 - A NR-CCE includes ~~an FFS~~ a positive integer number of PRBs (FFS: exact value)
 - FFS: whether a NR-CCE contains contiguous PRBs
 - FFS: whether multiple NR-CCEs may share one or more PRBs
 - FFS: whether NR-CCE is mapped on frequency-domain only or on both frequency and time-domain.

Agreement: UE-specific DL control information monitoring occasions at least in time domain can be configured

RAN1#87

Agreements:

- NR-PDCCH monitoring at least for single-stage DCI design,
 - NR supports the following minimum granularity of the DCI monitoring occasion:
 - For slots: once per slot
 - When mini-slots are used: FFS if every symbol or every second symbol
 - FFS with respect to which numerology if slot and mini-slot have different numerology (e.g. SCS, CP overhead)
 - Note: slot/mini-slot alignment is not assumed here
 - Note: This may not apply in all cases

Agreements:

- The time/freq. resource containing at least one search space is obtained from MIB/system information/implicitly derived from initial access information
- Time/freq. resource containing additional search spaces, can be configured using dedicated RRC signaling
- Other solution is not precluded

Agreements:

- The reference signals in at least one search space do not depend on the RNTI or UE-identity
 - FFS: The reference signals in at least an additional search space do not depend on the RNTI or UE-identity
- FFS: For one UE, there is the case the channel estimate obtained for one RE is reusable across multiple blind decodings involving that RE
- In an additional search space, reference signals can be configured, FFS: explicitly or implicitly

Agreements:

- At least for single-stage DCI design:
 - A control resource set (formerly called control subband) is, in the frequency domain, a set of PRBs within which the UE attempts to blindly decode downlink control information
 - The PRBs may or may not be frequency contiguous
 - A UE may have one or more control resource sets
 - Working assumption: One DCI message is located within one control resource set

- In frequency-domain, a PRB is the resource unit size (may or may not including DM-RS) for control channel

Agreements:

- NR should support dynamic reuse of at least part of resources in the control resource sets for data for the same or a different UE, at least in the frequency domain
 - FFS if resource reuse can be done in time domain as well
 - FFS: DL data DM-RS location in time should not vary dynamically as a consequence of dynamic reuse of control resources for data
 - FFS: time/frequency granularity of the resource reuse
 - FFS: signaling needed, if any

Agreements:

- when the control resource set spans multiple OFDM symbols, NR support a control channel candidate to be mapped to multiple OFDM symbols or to a single OFDM symbol
 - The gNB can inform UE which control channel candidates are mapped to each subset of OFDM symbols in the control resource set. FFS: details of the signaling (implicit or explicit)

RAN1 NR Ad-Hoc #1

Agreements

- NR supports at least following functionalities
 - At least for eMBB, in one OFDM symbol, multiple CCEs cannot be transmitted on the same PRB except for spatial multiplexing to different UEs (MU-MIMO)
 - A PDCCH candidate consists of a set of CCEs. A CCE consists of a set of REGs. A REG is one RB during one OFDM symbol.
 - For one UE, the channel estimate 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).
 - At least for DL data scheduled for a slot, the DL data DMRS location in time is not dynamically varying relative to the start of slot

Agreements:

- NR supports a 'group common PDCCH' carrying information of e.g. the slot structure.
 - If the UE does not receive the 'group common PDCCH' the UE should be able to receive at least PDCCH in a slot, at least if the gNB did not transmit the 'group common PDCCH'.
 - The network will inform through RRC signalling the UE whether to decode the 'group common PDCCH' or not
 - Common does not necessarily imply common per cell.
 - Continue the discussion on the detailed content of the 'group common PDCCH' including usage for TDD and FDD
 - The term 'group common PDCCH' refers to a channel (either a PDCCH or a separately designed channel) that carries information intended for the group of UEs.

Agreements:

- Each candidate of NR DL Control channel search space is composed by K NR-CCE(s)
 - A NR-CCE is defined in fixed number of REGs
 - FFS: Different REGs can be in the same or different symbols depending on REG to NR-CCE mapping
 - FFS: NR-CCE includes the REs assumed for UE-specific DMRS to demodulate that NR-CCE
 - FFS: REG to NR-CCE mapping within a control resource set is frequency first, time first or gNB configurable
 - FFS: Down selection of REG to NR-CCE mapping

- E.g. K can be 1, 2, 4, or 8, etc

Agreements:

- Transmit diversity scheme for DL control channel is supported.
 - FFS; SFBC or precoder-cycling, etc
 - Other schemes are not precluded
 - FFS number of antenna ports (1 or 2)
- A UE assumes fixed number of RS REs per REG for control channel rate matching when the REG contains RS REs
 - FFS; if the fixed number is configurable

Agreements:

- A control resource set is defined as a set of REGs under a given numerology
- Control search space includes at least the following properties
 - Aggregation level(s)
 - Number of decoding candidates for each aggregation level
 - The set of CCEs for each decoding candidate
- FFS: if any of the following properties belong to control resource set or control search space
 - Transmission/diversity scheme
 - CCE to REG mapping
 - RS structure
 - PRB bundling size
- FFS: if the control resource sets can overlap or not
- FFS: whether the mapping between control resource set and control search space is one-to-one or one-to-many

Agreements:

- The starting position of downlink data in a slot can be explicitly and dynamically indicated to the UE.
 - FFS: signaled in the UE-specific DCI and/or a 'group-common PDCCH'
 - FFS: how and with what granularity the unused control resource set(s) can be used for data

Agreements:

- The UE will have the possibility to determine whether some blind decodings can be skipped based on information on a 'group common PDCCH' (if present).
- FFS: if the data starting position is signaled on the group common PDCCH, the UE may exploit this information to skip some blind decodings
- FFS: if the end of the control resource set is signaled on the 'group common PDCCH', the UE may exploit this information to skip some blind decodings
- FFS: how to handle the case when there is no 'group common PDCCH' in a slot
- When monitoring for a PDCCH, the UE should be able to process a detected PDCCH irrespective of whether the 'group common PDCCH' is received or not

Agreements:

- 'Slot format related information'
 - Information from which the UE can derive at least which symbols in a slot that are 'DL', 'UL' (for Rel-15), and 'other', respectively
 - FFS: if 'other' can be subdivided into 'blank', 'sidelink', etc
- FFS: 'Control resource set duration'
 - FFS: Indicates the duration of the control resource set(s)
 - FFS: Can help the UE skip some of the semi-statically configured blind decodings. If not received, the UE performs all blind decodings.

RAN1#88

Agreements:

- At least QPSK is supported for the modulation of the PDCCH
- For the purpose of determining CCE size, at least one UE-specific DCI can be transmitted within one CCE (with QPSK and code rates not close to 1)
- An initial estimate of the number of REGs per CCE where a REG is one PRB in one OFDM symbol if DCI sizes are similar to LTE assuming QPSK: Suitable values could range from 4 to 8 REGs.
 - A more precise value needs more decisions on the information carried by the DCI

Agreements:

- NR-PDCCH can be mapped contiguously or non-contiguously in frequency
- The following may be considered to achieve the above (in the physical domain)
 - Option 1: Localized or distributed mapping of REGs to a CCE.
 - Option 2: Localized mapping of REGs to a CCE. Localized or distributed mapping of CCEs when multiple CCEs are needed for an NR-PDCCH
 - Down-selection between Opt 1 and Opt 2 should be further discussed
 - Companies are encouraged to perform evaluations considering aspects such as channel estimation, frequency diversity, impact of resource reuse for NR-PDSCH, etc., especially for one CCE case

Agreements:

- For single stage DCI, modulation scheme for PDCCH is only QPSK
- FFS for other modulation schemes for two-stage DCI if supported.

Agreements:

- Multiple control resource sets can be overlapped in frequency and time for a UE.
- A search space in NR is associated with a single control resource set
 - The search spaces in different control resources sets are defined independently.
- The max number of BD candidates for a UE is defined independently of the number of control resource sets and the number of search spaces.

RAN1 #88b

Agreements

- UE can be configured to "monitor DL control channel" in terms of slot or OFDM symbol with respect to the numerology of the DL control channel
 - Specification supports occasion of "DL control channel monitoring" per 1 symbol with respect to the numerology of the DL control channel
 - Note: This may not be applied to all type of the UEs and/or use-cases
 - FFS whether or not total number of blind decodings in a slot when a UE is configured with "DL control channel monitoring" per symbol can exceed the total number of blind decodings in a slot when a UE is configured with "DL control channel monitoring" per slot
- Data channel (PDSCH, PUSCH) duration and starting position
 - Specification supports data channel having minimum duration of 1 OFDM symbol of the data and starting at any OFDM symbol to below-6GHz, in addition to above-6GHz
 - Note: This may not be applied to all type of UEs and/or use-cases
 - UE is not expected to blindly detect the presence of DMRS or PT-RS
 - FFS: Whether a 1 symbol data puncturing can be indicated by preemption indication

- FFS: combinations of data duration and granularities of data position
- Specification supports data having frequency-selective assignment with any data duration
- FFS: relations between "DL control channel monitoring" occasions and data channel durations
- Note: this is addition to the agreements at RAN1#86.
- Note : 1-symbol case may be restricted depending on the BW.

Working assumption:

- One-port transmit diversity scheme with REG bundling per CCE is used for NR-PDCCH
 - FFS the bundling size
 - FFS: REG bundling is also for localized mapping in time and/or frequency-domain
- Companies are encouraged to provide evaluation results for 10 MHz and 20 MHz for larger aggregation levels and 5 MHz and 10 MHz for smaller aggregation levels

Agreements:

- MU-MIMO is supported NR-PDCCH using at least non-orthogonal DMRS.
 - FFS: orthogonal DMRS for UE-specific NR-PDCCH

Agreement: NR-PDCCH can be mapped contiguously or non-contiguously in frequency with localized or distributed mapping of REGs to a CCE (in the physical domain)

- Note: The number of contiguous REGs in the CCE needs further discussion.
- Note: Localized/distributed mapping can be achieved without/with interleaving.

Agreements (from offline):

- A CCE may be mapped to REGs with interleaved or non-interleaved REG indices within a CORESET
- Definition of a REG bundle: The UE may assume that the same precoder is used for the REGs in a REG bundle and that the REGs in a REG bundle are contiguous in frequency and/or time
- REG bundling per CCE is supported for NR-PDCCH
 - FFS: Whether this applies to common search space
 - FFS: Whether all REGs have DMRS or not
 - FFS: Whether wideband precoding is supported and the definition of a REG bundle if it is supported
 - FFS: whether REG bundle size is different for mapping of NR-PDCCH with or without interleaved mapping of CCE to REGs
 - FFS on REG bundle size
 - FFS whether REG bundle size is configurable

Working assumption:

- A NR-CCE is defined as 6 REGs
 - Candidate bundle sizes for distributed REG-to-CCE mapping: 2 or 3 REGs if NR-CCE is defined as 6 REGs
- FFS: impact of the NR-CCE definition on CORESET size, CCE aggregation levels, data resource allocation granularity, etc.

Agreements:

- From UE signaling perspective,
 - The higher layer signalling for the semi-static assignment of DL/UL transmission direction for NR can achieve at least the followings
 - A periodicity where the configuration applies;
 - FFS: Detailed periodicity set;
 - FFS: how to achieve the signaling of periodicity
 - A subset of resources with fixed DL transmission;

- FFS: The subset of resources can be assigned in granularity of slot and/or symbol;
- A subset of resources with fixed UL transmission;
 - Resources with fixed UL transmission happens in the ending part of the periodicity is supported;
 - FFS: The subset of resources can be assigned in granularity of slot and/or symbol;
- FFS: Other resources not indicated as "fixed UL" or "fixed DL" or "reserved/blank" can be considered as "flexible resource", where transmission direction can be changed dynamically.

Agreements:

- Strive for unified design regardless of whether the DL/UL resource partition is dynamic or semi-static
- UE behaviors at least the following are common regardless of whether the DL/UL resource partition is dynamic or semi-static:
 - Scheduling timing between control to the scheduled data
 - HARQ-ACK feedback including timing
- Strive for a limited number of semi-static DL/UL resource partition.
- NR may include tools motivated by either dynamic or semi-static.
- FFS: UE behavior if there is a conflict between dynamic and semi-static signaling.

Agreements:

- NR-PDSCH carrying the remaining minimum system information is scheduled using NR-PDCCH.
- NR-PBCH provides configuration information for the NR-PDCCH scheduling the NR-PDSCH carrying the remaining minimum system information
 - FFS if a part of configuration information can be derived by specification

Agreements:

- The broadcast delivery of other system information (OSI) is supported by NR-PDSCH transmission. The scheduling information of broadcast NR-PDSCH is considered to be carried by the following option(s):
 - Option 1: NR-PDCCH
 - Option 2: Remaining minimum system information
 - Other options are not precluded
- FFS: Maximum TBS for OSI.

Agreements:

- The search space of NR-PDCCH addressing the paging message can be configured by gNB
 - FFS detailed signaling mechanisms
 - FFS whether or not search space is shared for other usages

RAN1 #89

Agreements:

- CCE = 6 REGs (confirm Working Assumption)
- One of following is configured for REG-to-CCE mapping for a 1-symbol CORESET:
 - Opt.1: No interleaving – 6 REGs for a given CCE are grouped to form a REG bundle and all REGs for a given CCE are consecutive
 - CCE(s) of one PDCCH is/are also consecutive
 - FFS: Whether the UE can assume the same precoder across multiple REG bundles
 - Opt.2: Interleaving – [2 or 3 or 6] REGs for a given CCE are grouped to form a REG bundle and REG bundles are interleaved in the CORESET
 - FFS: Whether the UE can assume the same precoder across multiple REG bundles
 - FFS: down selection among {2}, {3}, {2,3}, {2,6}, {3,6}, {2,3,6}

- Note: UE can assume the same precoder within a REG bundle
- For REG-to-CCE mapping for a CORESET with more than 1-symbol;
 - REG bundle is defined in time and frequency-domain
 - At least support following:
 - Time-first mapping where one of the following is configured
 - Support REG bundle in time-domain being equal to the CORESET semi-statically configured time duration
 - Opt.1: Non interleaving - 6 REGs for a given CCE are grouped to form a REG bundle and all REGs for a given CCE are time and frequency localized
 - FFS: Whether the UE can assume the same precoder across multiple REG bundles
 - Opt.2: Interleaving – [2 or 3 or 6] REGs for a given CCE are grouped to form a REG bundle and REG bundles are interleaved in the CORESET
 - FFS: Whether the UE can assume the same precoder across multiple REG bundles
 - FFS: time-domain precoder-cycling
 - Support REG bundle in time-domain being equal to 1 symbol, or;
 - Support following:
 - REG-to-CCE mapping is exactly same as the case where a CORESET with 1 symbol
 - A PDCCH candidate can be mapped across OFDM symbols

Agreements:

- Confirm working assumption:
 - One-port transmit diversity scheme with REG bundling per CCE is used for NR-PDCCH
- FFS: DMRS RE overhead for the REG transmitting DMRS is 1/3
 - FFS on DMRS pattern

Agreements:

- In time domain, a CORESET can be configured with one or a set of contiguous OFDM symbols
 - The configuration can indicate the starting OFDM symbol and time duration
- A CORESET is configured with only one CCE-to-REG mapping

Working assumptions:

- For a time-duration of a CORESET:
 - Support 1-3 OFDM symbol as time duration for a CORESET on the NR carrier with less than or equal to X PRBs
 - Support 1-2 OFDM symbol as time duration for a CORESET on the NR carrier with wider than X PRBs
 - FFS: X values
 - FFS: Other time duration
 - FFS: Relationship of a first PDSCH DMRS symbol with one or more symbols of a CORESET for slot-based scheduling
 - FFS: restriction in the certain conditions

Agreements:

- Following contents are carried in NR-MIB
 - (Part of) SFN: [7 - 10] bits
 - At least 80 ms granularity
 - FFS: indication within 80 ms
 - [H-SFN: 10 bits]
 - RAN1 will ask RAN2

- Timing information within radio frame: [0 - 7] bits
 - E.g., SS block time index: [0 - 6] bits
 - E.g., half radio frame timing: [0 - 1] bit
- 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)
 - [Numerology of RMSI: [0 - 2] bits]
 - [Information regarding frequency resources for PDSCH scheduling: [x] bits]
- [Information regarding bandwidth part: [x] bits]
- [Information for quick identification that there is no corresponding RMSI to the PBCH: [0 - 1] bit]
- [Information for quick identification that UE can not camp on the cell: [0-1] bit]
 - RAN1 will ask RAN2
- [SS burst set periodicity: [0 - 3] bits]
- [Information on actual transmitted SS block(s): [0 - x] bits]
- [Area ID: x bits]
 - RAN1 will ask RAN2
- [Value tag: x bits]
 - RAN1 will ask RAN2
- [cell ID extension: x bits]
 - RAN1 will ask RAN2
- [Information on tracking RS: x bits]
- Reserved bits: [x > 0] bits
- CRC size for NR-MIB is [16 + y] bits

Agreements:

- For RMSI, the same subcarrier spacing is used for data and control channels
- For paging, the same subcarrier spacing is used for data and control channels
- RAN1 will strive to minimize the subcarrier spacing switching point during the initial access and idle mode
- FFS: Whether the subcarrier spacing of data and control channel is the same between RMSI and paging

Agreements:

- IS and OOS indications are based on SINR-like metric (e.g., hypothetical PDCCH BLER) as in LTE
 - SINR-like metric as in LTE represents whether or not UE can receive PDCCH
 - FFS: PDCCH in U-SS and/or PDCCH in C-SS
- RS used to derive SINR-like metric is down selected from following options
 - Opt.1: CSI-RS
 - Opt.2: DMRS for NR-PDCCH in C-SS
 - Opt.3: DMRS for NR-PBCH
 - Opt.4: NR-SSS
 - Opt.5: RS for time/frequency tracking (if separate RS from above is defined for time/frequency tracking)
 - FFS: how many options are used
- RAN1 assumes that single IS or OOS is indicated per reporting instance regardless number of beams available in cell. RAN1 has not concluded whether IS/OOS indications for RLF are per cell or not.
- RAN1 plans to provide at least periodic IS/OOS indications.
 - FFS: possibility of additional aperiodic IS indication e.g., based on beam failure recovery mechanism.

Agreements:

- For the reception of multiple NR-PDCCHs each scheduling a respective NR-PDSCH where each NR-PDSCH is transmitted from a separate TRP, NR supports:
 - The maximum supported number of NR-PDCCHs/PDSCHs is either 2 or 3 or 4
 - To be decided next meeting
 - FFS signaling (explicit or implicit) of the maximum number of NR-PDCCHs/PDSCHs for a UE, including the case of signaling a single NR-PDCCH/PDSCH

Agreements:

- To receive gNB response for beam failure recovery request, a UE monitors NR PDCCH with the assumption that the corresponding PDCCH DM-RS is spatial QCL'ed with RS of the UE-identified candidate beam(s)
 - FFS whether the candidate beam(s) is identified from a preconfigured set or not
 - Detection of a gNB's response for beam failure recovery request during a time window is supported
 - FFS the time window is configured or pre-determined
 - FFS the number of monitoring occasions within the time window
 - FFS the size/location of the time window
 - If there is no response detected within the window, the UE may perform re-tx of the request
 - FFS details
 - If not detected after a certain number of transmission(s), UE notifies higher layer entities
 - FFS the number of transmission(s) or possibly further in combination with or solely determined by a timer

RAN1 NR Ad-Hoc #2

Agreements:

For a 1-symbol CORESET with interleaving,

- At least REG bundle size = 2 is supported
- Working assumption:
 - REG bundle size = 6 is also supported
 - FFS whether configuration between 2 and 6 is explicit or implicit
 - Precoder granularity in frequency domain is equal to the REG bundle size in the frequency domain

For a 2 or 3 symbol CORESET with interleaving,

- At least REG bundle size = CORESET length is supported
- Working assumption:
 - REG bundle size = 6 is also supported
 - FFS whether configuration between CORESET length and 6 is explicit or implicit
 - Precoder granularity in frequency domain is equal to the REG bundle size in the frequency domain

Agreement

- DMRS is mapped on all REGs on all the OFDM symbols of a given PDCCH candidate
 - The DMRS density is the same on all REGs

Agreements:

- 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: Signalling details
- Note that the number of candidates can be zero
- UE blind decoding capability is known by NW
 - FFS: How the capability is derived

RAN1 #90

Agreements:

- Working assumptions are confirmed with the following details.
 - For 1/2/3-symbol CORESET, REG bundle size of 6 is supported.
 - A REG bundle size is as part of CORESET configuration for a CORESET configured by UE-specific higher-layer signalling.
 - FFS: CORESET(s) configured by non UE-specific signaling.
- FFS: UE assumes that precoder granularity in frequency domain is equal to the REG bundle size in the frequency domain
 - FFS: gNB can inform to the UE whether or not to assume the same precoder over multiple REG bundles.
- Note: more than one CORESET(s) with the UE-specific higher-layer signaling can be configured for the same UE

Agreements:

- Interleaving operates on REG bundles
 - FFS: interleaving in the case if and when gNB informs to the UE to assume the same precoder over multiple REG bundles

Agreements:

- For interleaving CORESET, the interleaving pattern is derived by the CORESET configuration and is not dependent on other CORESET configuration.
- Note: Following metrics can be considered
 - Good frequency distribution of REG bundles within the CORESET
 - Blocking probability for potential overlapped CORESET(s)
 - Inter-cell/inter-TRP interference randomization

Agreements:

- DMRS density for a CORESET is down-selected between 1/3 or 1/4.
 - FFS: need of additional DMRS density.

Working assumption:

- DM-RS density per REG is 1/4 at least for normal CP
 - FFS: orthogonal DMRS for MU-MIMO at RAN1 NR AH#3.
 - FFS: URLLC

Agreement:

- The CORESET used to schedule the PDSCH containing the RMSI can be configured to contain also UE-specific PDCCH(s)

Working assumptions:

- For slot-based scheduling, the first DMRS position either on 3rd symbol or 4th symbol is configured by [PBCH].
 - Maximum time duration of a CORESET is 2 symbols if the first DMRS position of a PDSCH with slot-based scheduling is on 3rd symbol, and is 3 symbols otherwise

- This replaces the past working assumption linking DMRS position to bandwidth X

Agreements:

- Supported aggregation levels for NR-PDCCH are at least 1, 2, 4, 8
- FFS 16 and 32 aggregation levels and also other numbers

Agreements:

- 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

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
 - FFS for non-slot based scheduling
 - FFS numerology specific X

Agreements:

- A UE can be configured by RRC signaling with one or more resource set(s)
 - The UE shall assume that the scheduled PDSCH is rate-matched around the resource set(s) when the scheduled PDSCH overlaps
 - FFS: exact configuration of a resource set including granularity.

Agreements:

- A UE can be configured by UE-specific RRC signaling to identify resource set(s) for which the PDSCH may or may not be mapped based on the L1 signaling.
 - For a scheduled PDSCH overlapping with given resource set(s), L1 signalling indicates whether the scheduled PDSCH is rate-matched around the resource set(s) or is mapped to the resources in the resource set(s).
 - FFS: details of the L1 signaling
 - FFS: exact configuration of a resource set including granularity

Agreements:

- At least the following is supported
 - When the scheduled PDSCH overlaps with the PDCCH scheduling the PDSCH, the UE shall assume that the scheduled PDSCH is rate-matched around the PDCCH scheduling the PDSCH
 - Other forms of resource sharing between PDCCH and PDSCH are not precluded

RAN1 NR Ad-Hoc #3

Agreements::

- Confirm the following working assumption:
 - DM-RS density per REG is 1/4 at least for normal CP.
 - FFS: orthogonal DMRS for MU-MIMO at RAN1 NR AH#3.

- FFS: URLLC
- DMRS density per REG for extended CP is same as that for normal CP

Working assumption:

- For a CORESET, precoder granularity in frequency domain is:
 - Configurable between i) equal to the REG bundle size in the frequency domain; or ii) equal to the number of contiguous RBs in the frequency domain within the CORESET
 - For ii), DMRS is mapped over all REGs within the CORESET.

Agreements:

- DMRS positions for PDCCH
 - ✧ **Working assumption:** Equally-distributed within a REG

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:

- At least two DCI sizes are defined.
 - One DCI size, which is at least for the purpose of fallback.
 - FFS: for other purposes.
 - One DCI size depending on configuration
 - FFS: whether both DL and UL have the same size or different.
 - FFS: for group-common DCI/PDCCH
 - Note: the UE is not necessarily required to monitor two DCI sizes at the same monitoring occasion

Agreements:

- In a given CORESET
 - ✧ Alt 1: different DCI formats
 - ✧ Alt 2: different search spaces
 can have different monitoring periodicities.
 - ✧ FFS which one

Agreement:

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