**3GPP TSG RAN WG1 #105-e R1-2106167**

**e-Meeting, May 10th – 27th, 2021**

**Agenda item:** 8.1.1

**Source:** Moderator (Samsung)

**Title:** Moderator summary for multi-beam enhancement: ROUND 3

**Document for:** Discussion and Decision

## Introduction

In this summary, the term “item 1” refers to the first item in the Rel.17 NR FeMIMO WID, i.e. multi-beam enhancement:

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| * Enhancement on multi-beam operation, mainly targeting FR2 while also applicable to FR1:   + Identify and specify features to facilitate more efficient (lower latency and overhead) DL/UL beam management to support higher intra- and L1/L2-centric inter-cell mobility and/or a larger number of configured TCI states:     1. Common beam for data and control transmission/reception for DL and UL, especially for intra-band CA     2. Unified TCI framework for DL and UL beam indication     3. Enhancement on signaling mechanisms for the above features to improve latency and efficiency with more usage of dynamic control signaling (as opposed to RRC)   + Identify and specify features to facilitate UL beam selection for UEs equipped with multiple panels, considering UL coverage loss mitigation due to MPE, based on UL beam indication with the unified TCI framework for UL fast panel selection |

This summary includes the following:

* Observation and proposal
* Summary of current companies’ positions on each of the aspects within the category

## Summary of companies’ inputs

The listed issues are structured primarily to facilitate some progress on pending issues identified in the agreements (see Appendix A).

### Issue 1 (Rel.17 unified TCI framework – note: for intra-cell beam management)

QCL for CA

*Current status from Round 1 discussion:*

**Proposal 1.3**: On Rel.17 unified TCI framework, for common TCI state ID update and activation to provide common QCL information and/or common UL TX spatial filter(s) across a set of configured CCs/BWPs

* The source RS determined from the indicated common TCI state ID to provide QCL Type-D indication and to determine UL TX spatial filter for a target CC can be configured in the target CC or other CC
* For intra-band CA, the source RSs determined from the indicated common TCI state ID to provide QCL Type-D indication and to determine UL TX spatial filter for the set of configured CCs are further associated with a same QCL-TypeD RS or a same UL TX spatial relation RS.
  + UE is expected to determine a single DL RX spatial filter and/or UL TX spatial filter for the set of configured CCs
* “A set of configured CCs/BWPs” includes all the BWPs in the set of configured CCs in one band

**Proposal 1.4**: For common TCI state ID update and activation to provide common QCL information and/or common UL TX spatial filter(s) across a set of configured CCs /BWPs:

* An RRC-configured TCI state pool can be configured in the PDSCH configuration (*PDSCH-Config*) for each BWP /CC as in Rel-15/16
* An RRC TCI state pool can be absent in the PDSCH configuration (*PDSCH-Config*) for each BWP /CC, and replaced with a reference to an RRC-configured TCI state pool in a reference BWP /CC
  + Introduce a UE capability for this option (details FFS)
* For an RRC-configured TCI state pool configured in a reference BWP/CC
  + When the BWP/CC ID for QCL-Type A/D source RS is absent in the TCI state, it implies that the target CC of the TCI state and the corresponding active BWP should be used to determine the source RS
    - Note: In such case, UE uses the corresponding active BWP ID + target CC ID + QCL-Type A/D RS source ID of the TCI state configured in the reference BWP in the reference CC to locate the corresponding QCL Type-A/D source RS
  + When the BWP /CC ID for QCL-Type D source RS is present in the TCI state, it is applied to all corresponding active BWP (s) of target CC(s)
  + Note that cross-CC UL power control indication is FFS as a separate issue
  + FFS: inter-band CA, e.g. two or more sets of configured CCs in a UE

Table 2 Additional inputs: issue 1 – Qualcomm’s note

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| --- | --- |
| **Company** | **Input** |
| Mod V0 | **Please share your inputs on proposals 1.3 (used to be 1.3A) and 1.4 (used to be 1.3X)** |
| Qualcomm | For Proposal 1.3, suggest the following change. We still do not see the benefit of mandating such configuration, which cannot ensure real common beam across CCs, since the QCL-D sources per CC can still indicate different Rx beams across CCs even the QCL-D source RSs across CCs share the same QCL-D source. To our understanding, the real common beam across CCs can be achieve by using the same QCL-D source RS across CCs, as in original agreement.   * ~~For intra-band CA,~~ Up to NW’s implementation, the source RSs determined from the indicated common TCI state ID to provide QCL Type-D indication and to determine UL TX spatial filter for the set of configured CCs can be ~~are~~ further associated with a same QCL-TypeD RS or a same UL TX spatial relation RS.   **Agreement**  On Rel-17 unified TCI framework, support common TCI state ID update and activation to provide common QCL information and/or common UL TX spatial filter(s) across a set of configured CCs:   * The above applies to intra-band CA * The above applies to joint DL/UL and separate DL/UL beam indications * Just as Rel.16, the RS in the TCI state that provides QCL-TypeA [or QCL-TypeB] shall be in the same CC as the target channel or RS * The common TCI state ID implies that the same/single RS determined according to the TCI state(s) indicated by a common TCI state ID is used to provide QCL Type-D indication and to determine UL TX spatial filter across the set of configured CCs * […] |
| OPPO | Copied some comments from the email discussion here and questions are added:  Re 1.3A:  it totally reverts the agreement made in 103e meeting. And the newly added wording “following the Rel-15/16 rules for cross-CC QCL indication” also revert the agreement.  What we agreed in 103e meeting is  ‘same/single RS determined ’ for multiple CCs. 1.3A reverts the agreement by the following ways:   * The QCL relationship is defined between A and B. The spec does not specify indirect QCL relationship. Specification in 38.214: “Each *TCI-State* contains parameters for configuring a quasi co-location relationship between one or two downlink reference signals and the DM-RS ports of the PDSCH, the DM-RS port of PDCCH or the CSI-RS port(s) of a CSI-RS resource”. When CSI-RS A is configured as QCL source for PDSCH, the QCL relationship is between DMRS of PDSCH and CSI-RS A. And the spec does not specify that the DMRS of PDSCH Is QCLed with the QCL source of CSI-RS A, i.e., the two-hop indirect QCL relationship is not specified. * The “indirect QCL” in 1.3A does not ensure same beam on multi-CCs: take an example: one CC1: PDSCH is QCLed with CSI-RS A and on CC2, PDSCH is QCLed with CSI-RS B. Both CSI-RS A and CSI-RS B are QCLed with SSB#1. Do the CC1 and CC2 use the same QCL-TypeD? The answer is no. Do the CC1 and CC2 use the same beam? The answer is also  no. * Regarding the newly added “following the Rel-15/16 rules for cross-CC QCL indication”: in rel-16, the cross-CC QCL indication only indicate TCI state ID for the set of CCs and those CCs are still applied with CC-specific TCI state/QCL.     And a couple questions to the proponents: take the following examples:   * In CC#1, the QCL-TypeD RS for PDSCH is CSI-RS #A and In CC#2, the QCL-TypeD RS for PDSCH is CSI-RS #B. And the QCL-TypeD RS for CSI-RS #A is SSB#1 and QCL-TypeRS for CSI-RS #B is SSB#1 too. In this example, which RS is the DMRS of PDSCH in CC#1 is QCLed w.r.t TypeD? And which RS is the DMRS of PDSCH in CC#2 is QCLed w.r.t TypeD? When the UE receives PDSCH in CC#1 and PDSCH in CC#2, can the UE assume a same QCL-TypeD applied on them. * The same question for PDCCH: in this example, CSI-RS #A is configured as the QCL-typeD RS for PDCCH in CC#1 and CSI-RS #B is configured as the QCL-TypeD RS for PDCCH in CC#2. Our question is：when the UE receives PDCCH on both CC#1 and CC#2, can the UE assume they have same QCL-TypeD? * Per our understanding, the answer to the above question is NO according to specification of QCL in 213 and 214.   Re proposal 1.4: Suggest to change the main bullet as follows. We do not need wording “a single RRC pool of TCI states” since the sub-bullets do not talk about that.  **Proposal 1.4**: ~~‘A single RRC pool of TCI states’~~ For common TCI state ID update and activation to provide common QCL information and/or common UL TX spatial filter(s) across a set of configured CCs /BWPs ~~is supported~~:  [Mod: Done] |
| Apple | Proposal 1.3: We do not agree with QC’s suggestion.  Direct and indirect QCL-TypeD are valid from simultaneous Rx point of view, which is defined in PDCCH+PDCCH QCL-TypeD collision handling rule in 38.213.  We support current proposal 1.3.  Proposal 1.4: We suggest clean-up the proposal as follows.  **Proposal 1.4**: Support the following options for TCI state list configuration in RRC     * Option 1: A TCI state list can be configured in the PDSCH configuration only in the BWP/CC with lowest BWP-ID and CC-ID across CCs in a band   + When the BWP/CC ID for QCL-Type A/D source RS is absent in the TCI state, it implies that the target CC of the TCI state and the corresponding active BWP should be used to determine the source RS     - Note: In such case, UE uses the corresponding active BWP ID + target CC ID + QCL-Type A/D RS source ID of the TCI state configured in the reference BWP in the reference CC to locate the corresponding QCL Type-A/D source RS   + When the BWP /CC ID for QCL-Type D source RS is present in the TCI state, it is applied to all corresponding BWP (s) of target CC(s)   + Note that cross-CC UL power control indication is FFS as a separate issue   + FFS: inter-band CA, e.g. two or more sets of configured CCs in a UE * Option 2: A TCI states list can be configured in the PDSCH configuration for each BWP /CC   + For TCI states configured in a BWP/CC,     - As in Rel-15/16, if the CC ID is absent in a TCI state, it applies to the serving cell in which the TCI -State is configured * Introduce UE capability to report whether UE supports option 1 or option 2 or both   [Mod: Please check current version based on MTK’s edit] |
| MediaTek | P1.3: Regarding the definition of “a set of configured CCs/BWPs”, we prefer to add back the clarification in the early version of this proposal. Regarding the comments from Qualcomm and OPPO, even we have same concern on this proposal doesn't reflect the previous agreement on the single TypeD RS across CCs, we see the use case may be limited if the second bullet of P1.3 is not agreed since only CSI-RS for BM can be used as a cross-CC TypeD RS in current supported QCL rule. We are open to discuss other solutions, but it might be difficult to converge.  **Proposal 1.3**: On Rel.17 unified TCI framework, for common TCI state ID update and activation to provide common QCL information and/or common UL TX spatial filter(s) across a set of configured CCs/BWPs, following the Rel-15/16 rules for cross-CC QCL indication   * The source RS determined from the indicated common TCI state ID to provide QCL Type-D indication and to determine UL TX spatial filter for a target CC can be configured in the target CC or other CC * For intra-band CA, the source RSs determined from the indicated common TCI state ID to provide QCL Type-D indication and to determine UL TX spatial filter for the set of configured CCs are further associated with a same QCL-TypeD RS or a same UL TX spatial relation RS. * “A set of configured CCs/BWPs” includes all the BWPs in the set of configured CCs in one band   [Mod: Done, let’s see if Ericsson is ok]  P1.4: For the main bullet, we share similar view with OPPO. For other bullets, we suggest the following changes:   * In Rel-15/16, TCI state pool is configured in the PDSCH configuration per BWP per CC. Thus, detail in the 3rd is not needed. * Regarding the UE capability, we don't see why UE capability is needed for per BWP per CC TCU pool configuration, which is the same in Rel-15/16.   **Proposal 1.4**: ~~‘A single RRC pool of TCI states’~~ For common TCI state ID update and activation to provide common QCL information and/or common UL TX spatial filter(s) across a set of configured CCs /BWPs ~~is supported~~:.   * An RRC TCI state pool can be configured in the PDSCH configuration (*PDSCH-Config*) for each BWP/CC, as in Rel-15/16. * An RRC TCI state pool can be absent in the PDSCH configuration (*PDSCH-Config*) for each BWP/CC, and replaced with a reference to an RRC TCI state pool in a reference BWP/CC.   + Introduce UE capability for this operation * For an RRC TCI state pool configured in a reference BWP/CC:   + When the BWP/CC ID for QCL-Type A/D source RS is absent in the TCI state, it implies that the target CC of the TCI state and the corresponding active BWP should be used to determine the source RS     - Note: In such case, UE uses the corresponding active BWP ID + target CC ID + QCL-Type A/D RS source ID of the TCI state configured in the reference BWP in the reference CC to locate the corresponding QCL Type-A/D source RS   + When the BWP/CC ID for QCL-Type D source RS is present in the TCI state, it is applied to all corresponding active BWP (s) of target CC(s)   + Note that cross-CC UL power control indication is FFS as a separate issue   + FFS: inter-band CA, e.g. two or more sets of configured CCs in a UE   [Mod: Done, plus Docomo’s suggestion and add FFS on UE cap] |
| ZTE | Proposal 1.3, we support the QC’s proposal, quite like that we have a requirement guaranteeing by NW as in Rel-16. But, for progress, we can live with previous version.  Proposal 1.4, we are fine the OPPO’s update. If going with Apple’s updated version, we wonder why we need a rule of ‘only in the BWP/CC with lowest BWP-ID and CC-ID across CCs in a band’. We prefer to have an explicit configuration for this case, e.g., introducing a reference CC ID and reference BWP ID parameter per BWP per CC. Then, compared with ‘option’, using ‘mode-1/2’ seems to be better considering we do not want to do any down-selection herein. |
| Docomo | We support the proposal 1.3A.  We actually prefer Qualcomm’s suggestion, but we are also fine with the current proposal. In Rel.15/16, it was up to gNB implementation whether CC-specific QCL-Type D RSs on different CCs are further associated to the same RS (e.g. SSB). However, it is “de facto” mandatory for gNB to configure the further association in CA, to let UE know the CC-specific QCL-Type D RSs on different CCs are the same QCL-Type D assumption. Thus, we don’t see much difference whether to adapt Qualcomm’s update or not, in practical operation.  Re OPPO’s comment:  As we commented multiple times, Proposal 1.3A says “*The determined CC-specific source RSs for the set of configured CCs/BWPs are further associated with a same QCL-TypeD RS*.”  Thus, it does not contradict with the previous agreement.  Re OPPO’s question:  In your example: when CSI-RS#A on CC1 is QCL-Type D RS of PDSCH/PDCCH DMRS and CSI-RS#B on CC2 is QCL-Type D RS of PDSCH/PDCCH DMRS, and both CSI-RS#A and CSI-RS#B are QCLed with the same SSB,   * Same as Rel.15, UE can receive PDSCHs/PDCCHs on CC1 and CC2 simultaneously, because PDSCHs/PDCCHs are assumed as the same QCL-Type D (indirectly). * This is typical Rel.15 gNB operation for CC-specific QCL type D configuration (QCL-Type A TRS + QCL-Type D TRS) to enable CA. * Please note that CC-specific QCL type D configuration are already supported and widely used in Rel.15, and it already supports CA operation. * Proposal 1.3A just reuses Rel.15/16 QCL rules.   Proposal 1.4: We are fine either of Apple’s update or MediaTek’s update. For MediaTek’s update, we’d like to update as “RRC-configured TCI state pool” or “~~RRC~~ TCI state pool”, to clarify that we don’t intend to introduce new terminology.  [Mod: Done] |
| LG | Fine with the current version of FL proposal 1.3 and we have a same understanding on the QCL rule of the proposal 1.3 with Docomo. |
| Ericsson | Proposal 1.3: Support. We think this is a good clarification of the earlier agreement, and it is how we interpreted that agreement: this is mandating a certain NW configuration which is typically not done in RAN1, but we were OK with that restriction already when the agreement was made, and we are still OK with it. We do not understand what “true common beam” in Qualcomm’s response means – could you clarify?  Proposal 1.4: We support Oppo’s proposal to remove ‘A single RRC pool of TCI states’.  Our thinking was that any CC where the PDSCH configuration includes TCI states would be a reference CC that could be referred to by another CC. We do not see that the addition in red in the original proposal is necessary: can someone explain? We also see this as a compromise between the ‘per CC’ and ‘across CC’ configuration options, since it provides a soft transition between the two.  We do not understand Apple’s proposal, where did the two options come from?  We would understand the need for a UE capability on the total number of configured TCI states across all CCs, where only the TCI states in reference CCs/BWPs would be counted.  [Mod: please check current version, 1.4 is based on MTK suggestion] |
| Spreadtrum | Proposal 1.3: We can support it in principle. In order to make sure that indirect QCL works, we suggest to add a clarification on UE behavior for indirect QCL as below,  **Proposal 1.3**: On Rel.17 unified TCI framework, for common TCI state ID update and activation to provide common QCL information and/or common UL TX spatial filter(s) across a set of configured CCs/BWPs, following the Rel-15/16 rules for cross-CC QCL indication   * The source RS determined from the indicated common TCI state ID to provide QCL Type-D indication and to determine UL TX spatial filter for a target CC can be configured in the target CC or other CC * For intra-band CA, the source RSs determined from the indicated common TCI state ID to provide QCL Type-D indication and to determine UL TX spatial filter for the set of configured CCs are further associated with a same QCL-TypeD RS or a same UL TX spatial relation RS.   + UE is expected to determine a single DL RX spatial filter and/or UL TX spatial filter for the set of configured CCs   Proposal 1.4: we support MTK’s suggestion.  [Mod: Make sense. Done] |
| Lenovo, Motorola Mobility | Proposal 1.3: support MediaTek’s version.  Proposal 1.4: support OPPO’s change to the main bullet. |
| Qualcomm | For Proposal 1.3, it would be good to have concrete examples to align understandings. Suppose we have two CCs. The examples for the two cases for FL’s 1.3 and quoted agreement are shown below to our understanding. The key difference is marked in red.  My points are: (1) Both cases are allowed in R15/16. So no need to mandate Case 1. We are fine to clarify both are NW’s choice. To DCM, I know Case 1 is your implementation. But Case 2 is also a valid config and can rigorously guarantee common Rx beam across CCs; (2) Especially to E///: Case 1 may not guarantee common PDSCH Rx beam for CC #1 and CC #2, because CSI-RS #1 an d #2 can indicate different PDSCH Rx beams, e.g. after P3 refinement, even they have same SSB as QCL-D. That is also why we prefer to at least allow Case 2, which guarantees common Rx beam for sure due to the same QCL-D RS.  Case 1: QCL-D per CC (2nd bullet in FL’s 1.3)  SSB #1 as QCL-D for CSI-RS for BM resource #1, which is as QCL-D for PDSCH on CC #1  SSB #1 as QCL-D for CSI-RS for BM resource #2, which is as QCL-D for PDSCH on CC #2  Case 2: Single QCL-D across CCs (quoted agreement)  SSB #1 as QCL-D for CSI-RS for BM resource #1, which is as QCL-D for PDSCH on CC #1  SSB #1 as QCL-D for CSI-RS for BM resource #1, which is as QCL-D for PDSCH on CC #2  So for Proposal 1.3, below is my suggestion to replace the original 2nd bullet. I didn’t hear any valid reason so far to forbid Case 2 above. Otherwise, we prefer to stick to the agreement, i.e. Case 2 only.   * ~~For intra-band CA,~~ Up to NW’s implementation, the source RSs determined from the indicated common TCI state ID to provide QCL Type-D indication and to determine UL TX spatial filter for the set of configured CCs can be ~~are~~ further associated with a same QCL-TypeD RS or a same UL TX spatial relation RS. * Up to NW’s implementation, the indicated common TCI state ID can provide a single source RS to determine QCL Type-D indication and to determine UL TX spatial filter for the set of configured CCs.   [Mod: I am not sure if this is acceptable to most companies. If this is up to NW implementation, there is no need to agree on this since there is no spec impact]  For Proposal 1.4   * We are fine for OPPO’s suggestion * Apple’s suggestion seems restrict 1 configure pool per band. To our understanding, this restriction may not be needed, since different bands can also share the same analog beam. Both we are fine for UE capability for supporting both * To MTK, we think UE capability for per BWP/CC pool is important. Because the shared pool is to reduce UE memory on the configured pool per BWP/CC. Say if UE must support per BWP/CC pool, it may need to reserve memory for 128 TCIs on every BWP/CC. If UE only supports shared pool, UE only needs to reserve memory for 128 (or slightly more) TCIs across multiple BWPs/CCs. That is why we prefer to allow UE capability only supporting the shared pool. To our understanding, shared pool is also beneficial for NW to reduce RRC overhead. * To E///, the red is the details on how the shared pool works. It almost converged after a long iteration. Without the clarification, how does UE interpretate the source RS in the TCI configured in the reference BWP/CC when applying it to a target BWP/CC? If the CC ID for a source RS is absent, UE should use the target CC ID, not the reference CC ID. Otherwise, Type-A RS does not work. Also, those notes/FFS are needed to address various concerns during the iteration.   So for 1.4, we are fine with either OPPO or MTK’s version with Apple’s capability suggestion, which is highlighted on top of MTK’s version below.  **Proposal 1.4**: ~~‘A single RRC pool of TCI states’~~ For common TCI state ID update and activation to provide common QCL information and/or common UL TX spatial filter(s) across a set of configured CCs /BWPs ~~is supported~~:.   * An RRC TCI state pool can be configured in the PDSCH configuration (*PDSCH-Config*) for each BWP/CC, as in Rel-15/16. * An RRC TCI state pool can be absent in the PDSCH configuration (*PDSCH-Config*) for each BWP/CC, and replaced with a reference to an RRC TCI state pool in a reference BWP/CC.   + Introduce UE capability for this operation * For an RRC TCI state pool configured in a reference BWP/CC:   + When the BWP/CC ID for QCL-Type A/D source RS is absent in the TCI state, it implies that the target CC of the TCI state and the corresponding active BWP should be used to determine the source RS     - Note: In such case, UE uses the corresponding active BWP ID + target CC ID + QCL-Type A/D RS source ID of the TCI state configured in the reference BWP in the reference CC to locate the corresponding QCL Type-A/D source RS   + When the BWP/CC ID for QCL-Type D source RS is present in the TCI state, it is applied to all corresponding active BWP (s) of target CC(s)   + Note that cross-CC UL power control indicate on is FFS as a separate issue   + FFS: inter-band CA, e.g. two or more sets of configured CCs in a UE   + UE reports capability for only supporting TCI states configured for each BWP/CC, only supporting TCI states configured in a reference BWP/CC and shared by multiple target BWPs/CCs, or supporting both   [Mod: Added FFS on UE cap on the sub-bullet of the second bullet. This should address your point. Details on UE cap are too premature and will cause endless discussion. We can discuss details in November/February] |
| Samsung | Proposal 1.3: We are fine with the proposal, but would like more clarity on “following the Rel-15/16 rules for cross-CC QCL indication” it would be better to list these rules are at least refer to part of the specification that includes the rules.  [Mod: removed since it can cause confusion]  Proposal 1.4: We are fine with Oppo’s change to remove “A single RRC pool of TCI states”.  We think that the sub-bullet of the third bullet is incomplete:   * + As in Rel-15/16, if the CC ID is absent in QCL-Info of a TCI state, ~~it applies to~~ the serving cell in which the TCI -State is configured is used to determine the source RS.   [Mod: removed] |
| Mod V16/17 | **Revised proposal per inputs**  **Re 1.3: Please check Qualcomm’s latest comment if you agree with it. If all proponents agree it is a NW implementation, I will remove proposal 1.3 since there is no need to agree on NW implementation issues which have no spec impact whatsoever.**  **DISCUSSION IS MOVED TO EMAIL REFLECTOR ROUND-3 SUB-THREAD 2. PLEASE COMMENT THERE.** |

The need for Notes proposed by Qualcomm

The following note (highlighted in yellow) was proposed by Qualcomm to be added at the end of the agreement to clarify the feasibility of a particular use case:

**Agreement**:

On Rel.17 unified TCI framework, for any DL RS that does not share the same indicated Rel-17 TCI state(s) as UE-dedicated reception on PDSCH and for UE-dedicated reception on all or subset of CORESETs in a CC, but can be configured as a target DL RS of a Rel-17 DL TCI (hence the Rel-17 DL TCI state pool), discuss and down-select by RAN1#106-e (August 2021) between the following two alternatives:

* Alt1. Rel-15/16 TCI state update signaling/configuration mechanism(s) are reused to update/configure the Rel-17 TCI state
* Alt2. Rel-17 TCI state update signaling/configuration mechanism(s) are used, e.g. with Rel-17 MAC-CE/DCI-based beam indication for Rel-17 joint/separate TCI

Note: The DL RS includes CSI-RS and DMRS for PDSCH or PDCCH

Note: For some channels/signals, only one of the above two alternatives may apply (to be discussed).

Note: The selected alternative can be used by NW implementation to align the Rel-17 DL TCI state between two target channels/signals

* E.g. TCI state #1 can be activated for PDCCH+PDSCH as in Rel-17 and can also be simultaneously configured for a CSI-RS resource for BM as in Rel-15/16.

Table 2 Additional inputs: issue 1 – Qualcomm’s note

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| **Company** | **Input** |
| Mod V0 | **Please share your input whether the Note is needed or not, or proposed rewording** |
| OPPO | (From ROUND 1) In our view, it is not needed because none of proposal 1.4/1.5/1.6 propose to restrict TCI states that can be configured to a channel or reference signal.  Any TCI state in the configured pool can be configured to a channel or CSI-RS as long as the QCL contained in that TCI state satisfies the QCL configuration types specified for each channel or CSI-RS resource. The wording in the Note might even cause some confusion, for example a TCI state with TypeA and TypeD activated for PDCCH+PDSCH cannot be configured for CSI-RS for tracking because the QCL type does not match. |
| Qualcomm | We are fine without any note if no company has different view. The note is because the understanding may be different based on some offline discussion with other companies. |
| Apple | Either to keep or remove the note is fine to us. |
| MediaTek | It is clear w/o the note. |
| ZTE | Either to keep or remove the note is fine to us. |
| Xiaomi | Either to keep or remove the note is fine to us. |
| Docomo | Either to keep or remove the note is fine to us. |
| Ericsson | Either to keep or remove the note is fine to us. |
| Spreadtrum | We can go with majority view. Slightly prefer to remove it. |
| Lenovo, Motorola Mobility | Either to keep or remove the note is fine to us. |
| Samsung | Note is OK but not needed. |
| Mod V16 | It seems all companies share the same understanding about the content of the Note (that the scheme from 1.6 can be used to achieve what Qualcomm has in mind via NW implementation). In that case, I don’t think the Note is needed.  **The Note will not be added to proposal 1.6. No more discussion is needed.** |
| Huawei, HiSilicon | We take that the note is not going to be included. We share our views here to keep some record and to avoid potential misunderstanding.  We are not sure about the impacts of such note. For example, whether it is going to affect the selection between Alt-1/2, whether it is going to enforce some requirements on Alt-2, and whether it would have some impact on supported QCL rules (e.g., thus far SSB cannot be used for explicit/direct QCL indication for PDSCH/PDSCH, and this note may imply such possibility). To sum up, we prefer not to add this note at this stage. |

### Issue 2 (L1/L2-centric inter-cell mobility)

*Current status from Round 1 discussion:*

**Proposal 2.1**: On Rel.17 beam indication enhancements for L1/L2-centric inter-cell mobility, support the following:

* At least for UE reception (on PDSCH) and transmission (on PUSCH) associated with UE-dedicated CORESETs, Rel-17 MAC-CE-based and DCI-based beam indication (at least using DCI formats 1\_1/1\_2 with and without DL assignment including the associated MAC-CE-based TCI state activation)
  + FFS (to be decided in RAN1#106-e): Whether this also applies to PDCCH and PUCCH
  + FFS: Whether the above is supported only for joint TCI, or both joint TCI and separate DL/UL TCI (including that, if separate DL/UL TCI is supported, the DL TCI and UL TCI associated with a same cell)
  + FFS: Whether to support activation of TCI states for more than one cells simultaneously
* The DL QCL and UL spatial relation rules already agreed for intra-cell scenario
* The use of SSB associated with a physical cell ID different from that of the serving cell as an indirect QCL reference for UE-dedicated PDSCH
  + FFS (to be decided in RAN1#106-e): Whether this also applies to UE-dedicated PDCCH
  + Note: When RS X is an indirect QCL reference of a target channel, there exists at least one other source signal on the QCL chain between RS X and the target channel
  + FFS (to be decided in RAN1#106-e): Whether SSB associated with a physical cell ID different from that of the serving cell can also be used as a direct QCL reference (source RS) for UE-dedicated PDCCH/PDSCH

**Proposal 2.2**: On Rel.17 L1-RSRP multi-beam measurement/reporting enhancements for L1/L2-centric inter-cell mobility and inter-cell mTRP, decide by RAN1#106-e whether to support the following RS types as measurement RS or not:

* CSI-RS for mobility/RRM configured for or QCLed with a non-serving cell
* CSI-RS for BM configured for a non-serving cell or QCLed with a non-serving cell SSB
* CSI-RS for tracking configured for a non-serving cell or QCLed with a non-serving cell SSB

Note: If another beam metric other than L1-RSRP is supported (e.g. L3-RSRP is still FFS), the above also applies

Table 3 Additional inputs: issue 2

|  |  |
| --- | --- |
| **Company** | **Input** |
| Mod V0 | **Please share your input on the above proposals** |
| Qualcomm | For Proposal 2.2, we suggest the same change for CSI-RS for mobility/RRM, since “associated with” may have different interpretations. Also, we are fine to put CSI-RS for BM as FFS, since CSI-RS for BM might be beneficial to identify P2 beams within the non-serving SSB to our understanding.  CSI-RS for mobility/RRM ~~associated with~~ configured for or QCLed with a non-serving cell  [Mod: Done] |
| Apple | For proposal 2.1, we suggest we remove the note or change it as follows  “FFS: additional impact if serving cell and/or RNTI change is supported”  [Mod: Done]  For proposal 2.2, support. |
| ZTE | Regarding proposal 2.1, as we mentioned many time before, ‘the assumption about the change of serving cell/RNTI or not’ are not necessary. If required, we can further study this issue after receiving RAN2-LS. We are fine with other bullets.  Regarding proposal 2.2, ‘configured for’ a non-serving cell SSB is confusing. Does it mean that …. Configured for non-serving cell or QCLed with a non-serving cell SSB?  [Mod: see latest version per QC’s 2nd suggestion] |
| Xiaomi | As for proposal 2.2, we want to clarify the difference of “ …for L1/L2-centric inter-cell mobility” and “…for inter-cell mTRP” in the main bullet. In my understanding, “ …for L1/L2-centric inter-cell mobility” means the measurement/reporting is used for select a non-serving cell, while “…for inter-cell mTRP” means the non-serving cell has been configured as one TRP to the UE for transmission/reception. If my understanding is right, can we move “ and inter-cell mTRP” in the main bullet or provide two proposals for these two scenarios separately. Since we think CSI-RS for BM configured for or QCLed with a non-serving cell SSB can be supported for P2 beam management of the non-serving cell.  [Mod: From RAN1 perspective, IMO there is no difference since what we will specify simple enables DPS-like operation – both reporting/measurement and beam indication. Whether SC is changed or not is a RAN2 issue. So from RAN1 perspective, no difference between L12XCM and XC-mTRP – other than the assumed TCI framework.]  If my understanding is wrong, please feel free to let me know, thanks! |
| Docomo | Support the proposals. |
| CMCC | For proposal 2.2, we think “configured for a non-serving cell” is not clear to us. What is the difference between “configured for a non-serving cell” and “QCLed with a non-serving cell SSB”? If they are the same, we can just keep one of them.  [Mod: If I understand correctly (this wording came from the inputs in the previous rounds), an RS can be configured for the SC but QCLed with a non-serving SSB. Or it can be simply an RS configured for a NSC.] |
| LG | On Proposal 2.1, we have a similar view with ZTE related to the change of SC/RNTI that it is reasonable to further discuss depending on the result of RAN2 LS.  On Proposal 2.2: Support |
| Ericsson | Proposal 2.1: Support, with the following modification:  In RAN2 we have the following agreement:   * RAN2 confirm the simplified procedures on the L1L2 mobility model as a baseline RAN2 understanding:   Scenario 2: L1L2 mobility model (i.e. with serving cell change)  1. UE receives from serving cell, configuration of SSBs of the cell with different PCI for beam measurement/ serving cell change.  2. UE performs beam measurement for the cell with different PCI and report it to serving cell.  3. Serving cell configuration for cell with other PCI is provided to the UE by RRC (pre-configuration for serving cell change, FFS if this step is same as 1).  4. Based on the above reports, TCI states for cell with different PCI is activated along with the serving cell change (by L1/L2 signaling). FFS if this is multiple steps.  5. UE changes the serving cell and starts receiving/transmitting using the pre-configured UE-dedicated channel and TCI states.  So RAN2 has agreed to facilitate serving cell change. The note is thus irrelevant. However, the case without update on RNTI is possible:   * R2 didn’t see a problem with using different C-RNTIs for different cells. Different C-RNTI seems more natural in a mobility scenario. No conclusion in R2 for mTRP scenario. * RRC configurations of the cells for L1/L2 centric mobility, including C-RNTI, are configured by RRC.   So the C-RNTI in the different cells is up to NW configuration.  Therefore, we propose to modify the note:   * Note: It is assumed that RNTI(s) are not mandated to change when L1/L2-centric inter-cell mobility is configured and utilized   [Mod: The Note is now removed per inputs from a number of companies]  Proposal 2.2: Support |
| Spreadtrum | Proposal 2.1: Support in principle. We have a clarification question, is it correct that all the target channels are configured the same way as in serving cell, and UE can determine the target channel transmitted from non-serving cell only by the QCL configuration?  [Mod: Correct. Indirect QCL]  Proposal 2.2: Support, since the decision will be made in the next meeting. |
| Lenovo, Motorola Mobility | Proposal 2.1: The note is related to RAN2’s decision on L1/L2-centric intercell mobility. Clarification from RAN2 is required. We suggest to put this bullet under FFS.  [Mod: Removed]  Proposal 2.2: Support |
| Nokia | Resuming to the latest proposal circulated on the email reflector, as a sign of progress, we could accept something along the highlighted lines below. This is coming from our initial position that in fact the whole first bullet could be deleted as there is no clear evidence on many factors mentioned inthere: performance of data and control channels, reuse of the Rel17 TCI framework, etc.  Re: E///: we are not OK to advertise inhere RAN2 agreements from this meeting. When the LS is coming from RAN2, we are happy to work on that, until then, we think RAN2 continues the discussion on this topic and further agreements may be possible.  **Proposal 2.1**: On Rel.17 beam indication enhancements for L1/L2-centric inter-cell mobility, support the following:   * At least for UE reception (on PDSCH ~~and PDCCH~~) and transmission (on PUSCH ~~and PUCCH~~) associated with UE-dedicated CORESETs, Rel-17 MAC-CE-based and DCI-based beam indication (at least using DCI formats 1\_1/1\_2 with and without DL assignment including the associated MAC-CE-based TCI state activation)   + FFS (to be decided in RAN1#106-e): Whether this also applies to PDCCH and PUCCH   + FFS: Whether the above is supported only for joint TCI, or both joint TCI and separate DL/UL TCI (including that, if separate DL/UL TCI is supported, the DL TCI and UL TCI associated with a same cell)   + FFS: Whether to support activation of TCI states for more than one cells simultaneously * The DL QCL and UL spatial relation rules already agreed for intra-cell scenario * The use of SSB associated with a physical cell ID different from that of the serving cell as an indirect QCL reference for UE-dedicated ~~PDCCH/~~PDSCH   + FFS (to be decided in RAN1#106-e): Whether this also applies to UE-dedicated PDCCH   + Note: When RS X is an indirect QCL reference of a target channel, there exists at least one other source signal on the QCL chain between RS X and the target channel   + FFS (to be decided in RAN1#106-e): Whether SSB associated with a physical cell ID different from that of the serving cell can also be used as a direct QCL reference (source RS) for UE-dedicated PDCCH/PDSCH * Note: It is assumed that serving cell and/or RNTI(s) are not mandated to change when L1/L2-centric inter-cell mobility is configured and utilized   [Mod: Thanks for Nokia’s understanding. Indeed, this is a good compromise. Also, the Note is now removed so there is no risk in falling into what you are concerned about (RAN2 agreement advertisement).] |
| Qualcomm | For Proposal 2.2, suggest the following highlighted changes to clarify ZTE’s question if that is the common understanding.  **Proposal 2.2**: On Rel.17 L1-RSRP multi-beam measurement/reporting enhancements for L1/L2-centric inter-cell mobility and inter-cell mTRP, decide by RAN1#106-e whether to support the following RS types as measurement RS or not:   * CSI-RS for mobility/RRM associated with a non-serving cell * CSI-RS for BM configured for a non-serving cell or QCLed with a non-serving cell SSB * CSI-RS for tracking configured for a non-serving cell or QCLed with a non-serving cell SSB   Note: If another beam metric other than L1-RSRP is supported (e.g. L3-RSRP is still FFS), the above also applies  [Mod: Done] |
| Samsung | Proposal 2.1: Support  RAN2 has defined two scenarios. The first scenario requires no-serving cell change. The second requires serving cell change. This is up to RAN2. We are also fine with the suggestion proposed by Ericsson.  [Mod: Note is removed now.]  Proposal 2.2: Support |
| Mod V16/17 | **Revised per inputs**  **DISCUSSION IS MOVED TO EMAIL REFLECTOR ROUND-3 SUB-THREAD 1. PLEASE COMMENT THERE.** |

### Issue 3 (signaling medium)

Below is the current outcome of the offline discussion.

**Modified OptB:**

On Rel-17 unified TCI framework, for a UE configured with both joint TCI and separate DL/UL TCI, an activated TCI state (via MAC-CE-based TCI state activation) can be a TCI state associated with either joint TCI or separate DL/UL TCI

* Detailed MAC-CE-based design for the above functionality is up to RAN2
* FFS: the cases of M or N > 1, if supported

Table 4 Additional inputs: issue 3 – switching

|  |  |
| --- | --- |
| **Company** | **Input** |
| Mod V17 | OptA (original proposal 3.3, chairman notes):   * Support: CATT, CMCC, Ericsson, Fraunhofer IIS/HHI, Fujitsu, Futurewei, Huawei, HiSi, IDC, LG, MTK, NEC, NTT Docomo, OPPO (fine), Qualcomm, Samsung, Spreadtrum, Xiaomi, ZTE   OptB (without UE-capability on mixed activation):   * Support: Apple, Convida, Intel, Lenovo/MoM, Nokia/NSB, Sony   Modified OptB (with UE-capability on mixed activation):   * Support/ok: Convida, Fraunhofer IIS/HHI, Intel, MTK, Nokia/NSB, [Qualcomm,] Samsung, Sony, Spreadtrum, ZTE * Concern: LG, Huawei/HiSi, vivo   **Please share your view** |
| Nokia | Re Opt B above: I do not like to see the additional capabilities mentioned in Opt B, but on the other hand I suppose this is the extra mile Option B is proposing w.r.t Option A, acknowledging that flexibility does not come for free. Another observations is that the configuration examples described above are more indicative for the RAN2 implementation and not binding to such particular configuration, so it is more for the detailed MAC-CE design to take this into consideration. We could support such direction.  [Mod: Thank you for your understanding] |
| Convida Wireless | We can also support the Modified OptB. |
| Huawei, HiSilicon | As discussed in offline email, here are some technical comments from our side.  1. We are still not sure whether dynamic switching between joint and separate TCI at DCI level is justified by the use cases listed (i.e., asymmetric DL/UL in HetNet, DL and UL from different TRPs, and MPE event). We share similar understanding as several other companies that MAC-CE based switching between joint and separate TCI is sufficient in these cases.  2. During the offline discussion, Qualcomm asked whether any UE vendor is willing to support such dynamic switching between joint and separate TCI. Therein, we heard several UE vendors shared their views on increased complexity and they can be ok only after UE feature is added to allow them not supporting this feature, with which the implementation support of this mixed case is not justified.  3. We understand many things are possible; still we share similar view as several other companies that adding the support of such mixed case to the TCI activation MAC-CE in R17 would lead to increased signaling overhead, even when this case is not enabled, and hence not preferred especially when the use case and implementation support are unclear. We understand Intel intends to reuse the activation MAC-CE for mTRP, but that has not been agreed, and we have doubt on the feasibility given the various new features introduced in R17.  4. In addition, on modified OptB, we are not sure whether it is a good idea to mix companies’ views on “support” and “ok”…  [Mod: We will do overall temp check again on OptA vs Modified OptB online.] |
| Qualcomm | Introducing a capability for simultaneously activating joint and separate TCI may not be liked by some companies including us but it may hopefully help the progress. Similar to MTK/Vivo/HW/LG/…, we do not prefer this mixed mode. To our understanding, activating multiple TCIs is mainly for fast beam switch or simultaneous Tx/Rx for reliability/throughput. However, activating both joint and separate TCI for potential infrequent event like MPE may unnecessarily consume UE resource/power. The mixed mode may also complicate MAC-CE design at least when separate pools are used for joint/separate TCI. In this case, the MAC-CE may need to provide pool ID per activated TCI, while Option A may only need 1-bit TCI type indication for all activated TCIs. So our 1st preference is still Option A.  Also Option B may need to discuss more issues as suggested changes in red below.   * As in the 1st new bullet, we need to answer if UE receives a separate DL TCI after a joint TCI, should UL channel stay with the old joint TCI, or should UE ignore the separate DL TCI. * As in the 2nd new bullet, we need to answer whether to introduce UE capability on max active QCL #, which includes all activated joint and separate TCIs. There might be more from other companies, so Option A seems simpler. * For TCI state activation and indication, following cases are included (via NW implementation):   + At least one activated TCI state is associated with joint TCI and at least another activated TCI state is associated with separate DL/UL TCI     - The TCI field in DCI formats 1\_1/1\_2 used for beam indication can indicate a TCI state(s) associated with either joint TCI or separate DL/UL TCI.     - Simultaneous ~~A~~activation of TCI states where at least one activated TCI state is associated with joint TCI and at least another activated TCI state is associated with separate DL /UL TCI is an optional UE capability     - When a DCI first indicates a joint TCI for a set of DL and UL channels/RSs       * If a later DCI only indicates a separate DL TCI for the same set of DL channels/RSs as that for the joint TCI         + UE will apply the separate DL TCI to the set of DL channels/RSs, and will still apply the joint TCI to the set of UL channels/RSs       * If a later DCI only indicates a separate UL TCI for the set of DL channels/RSs as that for the joint TCI         + UE will apply the separate UL TCI to the same set of UL channels/RSs, and will still apply the joint TCI to the set of DL channels/RSs     - Introduce UE capability on       * # of active QCL assumption per BWP/CC, which is defined as total number of activated joint TCI and separate DL TCI per BWP/CC       * # of active spatial relation per BWP/CC, which is defined as total number of activated joint TCI and separate UL TCI per BWP/CC   [Mod: I removed the entire bullet on NW implementation (it was started by me – which is a mistake). There is no need to describe what is possible by NW implementation in an agreement. I moved the UE cap bullet outside. I suggest we postpone detailed proposals on UE cap until UE feature session for Rel-17 starts..] |
| LG | We share a similar view with Huawei/Qualcomm that it is still doubtful to work in an efficient manner considering MAC CE impact with the design of separate TCI state pools, the limited number of TCI codepoints and the additional consumption of UE resources for handling a specific scenario intermittently. |
| Mod V25 | **Revised proposal** – removed bullet on NW implementation to avoid confusion and starting too much discussion |

### Issue 4 (MPUE)

### Issue 5 (MPE)

**Proposal 5.1**: On Rel.17 enhancements to facilitate MPE mitigation, support [one of] the following schemes [(to be down-selected in RAN1#106-e)]:

* Opt1A. {Rel.16 P-MPR based (TCI or SSBRI/CRI-specific)} + Virtual PHR or a modified version
  + The modified version may be associated with each activated UL TCI or, if applicable, joint TCI, or associated with each of the reported SSBRI(s)/CRI(s) and/or panel indication (if configured) from candidate pool, if reported.
  + The reporting reuses the event-driven mechanisms from the Rel-16 P-MPR reporting
  + FFS: Definition of virtual PHR and how it is used
* Opt2A. Reporting at least {SSBRI(s)/CRI(s)} (beam/panel level) to indicate gNB beam(s) that are preferred for UL transmission in NW-initiated CSI-report on PUCCH/PUSCH
  + Down-select one option from the followings by RAN1#106-e:
    - Alt1: In a single reporting instance, reporting SSBRI(s)/CRI(s) to indicate gNB beam(s) that is preferred for UL transmission + offsetting L1-RSRP that accounts for MPE effect associated with the SSBRI(s)/CRI(s)
      * FFS: how the offsetting L1-RSRP is calculated with regard to MPE effect
    - Alt2: In a single reporting instance, reporting SSBRI(s)/CRI(s) to indicate gNB beams that is preferred for UL transmission, DL reception (only), or both + L1-RSRP associated with the SSBRI(s)/CRI(s) + virtual PHR or a modified version
      * For each reported SSBRI/CRI, UE determines whether virtual PHR or a modified version associated with the SSBRI/CRI is reported
      * For virtual PHR or a modified version, reuse the same definition in Opt1A
      * FFS: how to inform NW whether a virtual PHR or a modified version is reported or not
    - Alt3: In a single reporting instance, reporting SSBRI(s)/CRI(s) to indicate gNB beams that is preferred for UL transmission, DL reception (only), or both + L1-RSRP associated with the SSBRI(s)/CRI(s) for DL reception
      * FFS: how to inform NW whether a reported SSBRI/CRI is preferred for UL transmission or preferred for DL reception (only)
      * FFS: whether/what to report using bit field for L1-RSRP for UL transmission
* Note:  The determination of power backoff due to power management defined in RAN4 specification is unchanged and reused for Rel-17 enhancements on MPE mitigation

Table 5 Additional inputs: issue 5 – MPE

|  |  |
| --- | --- |
| **Company** | **Input** |
| Mod V17 | I received some offline inputs on Opt2A text (red).  **Please share your view on the above proposal** |
| Huawei, HiSilicon | We have concerns on the proposal above.  1. The proposal did not specify how to modify virtual PHR or L1-RSRP to account for MPE, and the feasibility should be checked by RAN4 before agreed upon (as RAN4 has been the responsible WG for MPE since R15).  2. Previous version of Opt 2A is to report alternative UE Tx panel/beam, as MPE is more related to UE Tx panel/ beam, while it now mainly focuses gNB beam that is preferred by the UE. This is a sharp change, which may restrict gNB implementation, and is hence not preferred.  Our preference is Opt 1D, and for the sake of progress, we suggest sending the three alternatives agreed in previous meeting (plus additional information if needed) to RAN4 for them to check and confirm feasibility, before proceeding to detailed signaling design. |
| Qualcomm | Support Proposal 5.1 in general |
| MediaTek | Support either both Opt1/Opt2A or Opt2A-only  We fail to see how Opt1 can mitigation MPE issue if it is supported as standalone w/o Opt2A. In current spec, both reported SSBRI(s)/CRI(s) and the activated UL TCI are selected based on L1-RSRP reporting for DL without considering any MPE effect. Then, how to find out an alternative UE Tx panel/beam based on them even more PMPR or virtual PHR is provided for them.  Re HW’s comment, according to precious agreement, Opt2A is to report feasible “gNB beam” for UL transmission, and we don't see how this can restrict gNB implementation. To our understanding, selection of DL RS in beam reporting is equivalent to selection of gNB beam.  **Agreement**  On Rel.17 enhancements to facilitate MPE mitigation,   * On further enhancing the P-MPR report in Rel.16 (already agreed RAN4 framework, including triggering), down select between beam-level and panel-select reporting * On SSBRI(s)/CRI(s) and/or indication of panel selection, focus study on the following:   + Reporting of at least SSBRI(s)/CRI(s) to indicate gNB beam(s) that is feasible for UL transmission: additional reporting quantities are FFS   + Reporting of at least an indicator associated with a UE ‘panel’ that is feasible for UL transmission: additional reporting quantities are FFS * Note: Just as agreed in RAN1#103-e, the purpose is to assess whether specification is needed or not |
| LG | Support Proposal 5.1 in principle. On Alt3 of 2A, L1-RSRP is reported for DL reception. For UL transmission, however, it is still open issue whether/what to report using the bit field for L1-RSRP to our understanding. We’d like to suggest the following change on Alt3.   * Alt3: In a single reporting instance, reporting SSBRI(s)/CRI(s) to indicate gNB beams that is preferred for UL transmission, DL reception (only), or both + L1-RSRP associated with the SSBRI(s)/CRI(s) for DL reception   + FFS: how to inform NW whether a reported SSBRI/CRI is preferred for UL transmission or preferred for DL reception (only)   + FFS: whether/what to report using bit field for L1-RSRP for UL transmission |
| Mod V25 | **No change in proposal** |

## Appendix

Issue 3:

**OptA (original proposal 3.3)**

On Rel-17 unified TCI, for a UE configured with both joint TCI and separate DL/UL TCI ~~(including DL-only TCI, UL-only TCI, or DL+UL TCI)~~, TCI states can be activated via MAC-CE-based TCI state activation for either only joint DL /UL TCI or only separate DL /UL TCI

* When TCI states are activated for joint TCI, the TCI field in DCI formats 1\_1/1\_2 used for beam indication can update only a TCI state associated with joint TCI
* When TCI states are activated for separate DL/UL TCI, the TCI field in DCI formats 1\_1/1\_2 used for beam indication can update only a TCI state associated with either DL-only TCI or UL-only TCI, or update a pair of TCI states associated with DL TCI and UL TCI, respectively
* Detailed MAC-CE-based design is up to RAN2
* FFS: the cases of M/N > 1, if supported