**3GPP TSG RAN WG1 Meeting #109-e R1-220XXXX**

**e-Meeting, May 9th – 20th, 2022**

**Source: Moderator (Lenovo)**

**Title: Feature lead summary #1 on multi-cell PUSCH/PDSCH scheduling with a single DCI**

**Agenda item:** **9.10.1**

**Document for:** **Discussion and Decision**

# Introduction

This document summarizes the contributions submitted under the “9.10.1 **Multi-cell PUSCH/PDSCH scheduling with a single DCI**” agenda item of the Rel-18 work item on “Multi-Carrier Enhancements (MCE) for NR”.

The Rel-18 WI Multi-carrier enhancements was agreed during RAN#94-e meeting [1], where one of the objectives is targeted to specify a solution for multi-cell PUSCH/PDSCH scheduling with a single DCI. The detailed objectives in the WID are listed below:

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| **1. Specify a solution for multi-cell PUSCH/PDSCH scheduling (one PDSCH/PUSCH per cell) with a single DCI [RAN1]**   * **Identify the maximum number of cells that can be scheduled simultaneously** * **Consider both intra-band and inter-band CA operation** * **Consider both FR1 and FR2** * ***The single DCI shall be optimized for 3 or more cells for the multi-cell PUSCH/PDSCH scheduling*** |

The following e-mail thread for Multi-cell PUSCH/PDSCH scheduling with a single DCI is announced by chairman in RAN1#109-e:

[109-e-R18-MC\_Enh-01] Email discussion on multi-cell PUSCH/PDSCH scheduling with a single DCI by May 20 – Haipeng (Lenovo)

* Check points: May 12, May 18, May 20

In this contribution, we summarize the related issues and proposals based on the contributions submitted in RAN1#109-e under the agenda item 9.10.1 [1]-[25]. The whole feature lead summary is structured as follows:

From section 2 to 5, the main issues raised by company contributions are divided into 4 parts and each section covers one main issue. In each section, the background and related proposals submitted in this meeting are listed firstly in sub-section X.1, then summary on one or several sub-issues is provided in sub-section X.2 from moderator’s perspective. Based on the above summary, in sub-section X.3, a set of proposals is recommended by moderator followed by one or multiple tables to collect company views for the initial proposals in the first round of e-mail discussion. If present, in sub-section X.4 the proposals will be updated based on companies’ inputs. As e-mail discussion goes on, more sub-sections may be provided for further e-mail discussion and update.

In section 6, some proposals will be selected for discussion in the GTW session.

In Section 8, the agreements made in previous RAN1 meetings are listed for reference.

Companies are highly encouraged to provide views within 24h. Moderator will try to update the proposals based on companies’ inputs at least on a daily basis.

# Scenarios and basic framework

## Background and submitted proposals

Regarding this issue, companies’ views are summarized as below:

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| * **Huawei, HiSilicon** * *Proposal 4: The scenario of same SCS among scheduling and scheduled cells can be prioritized in Rel-18.* * *Proposal 8: In R18 the four cases can be supported for multi-cell scheduling by single DCI.* * *Opt 1: Single PDCCH in PCell scheduling PCell+SCell* * *Opt 2: Single PDCCH in PCell scheduling SCell1+SCell2* * *Opt 3: Single PDCCH in SCell scheduling PCell+SCell* * *Opt 4: Single PDCCH in SCell1 scheduling SCell1+SCell2 or SCell1 scheduling SCell2+SCell3* * **ZTE** * *Proposal 1: For the multi-cell scheduling, scenario 1 should be supported and scenario 2 and scenario 3 can be considered if time allows in this WID.* * **Nokia, Nokia Shanghai Bell** * *Proposal 2.1: Focus the discussions in the early WI phase on overarching principles for multi-cell PDSCH/PUSCH scheduling incl. overall scheduling framework for a cell, intended application scenarios and multi-cell DCI design framework assumptions before discussing the details of the multi-cell DCI content DCI field per DCI field.* * *Proposal 2.2: The Rel-15…Rel-17 cross-carrier scheduling framework applies as-is; The multi-cell DCI is considered the scheduling DCI, and the PDCCH transmitting it is considered the scheduling PDCCH and the scheduled PxSCH processing and timelines as specified for cross-carrier scheduling are used the same way as with single-cell DCI.* * *Proposal 3.5.1: The design of the MC-DCI should allow for optimization of the MC-DCI size when all cells within the MC-DCI have some commonalities, e.g. same numerology and duplexing mode. Note these optimizations need not be limited to intra-band case.* * **Spreadtrum Communications** * *Proposal 1: It is suggested to study and decide the scope of multi-cell combinations via one single DCI scheduling, to do down select among all those conditions:*   + *FR1 and FR2*   + *Intra-band and inter-band*   + *PCell scheduled by sSCell in FR2*   + *Licensed and unlicensed CCs*   + *Belong to Different TAG cells*   + *CCs from same PUCCH group or different PUCCH group*   + *Different priority scheduling* * *Proposal 2: Scenario#3 PCell scheduled by sSCell in FR2 can be with lower priority* * *Proposal 3: For Scenario#7 Different priority scheduling can be with lower priority* * *Proposal 4: Multiple cells scheduled by one DCI should belong to the same PUCCH group* * **Vivo:** * *Proposal 1. For multi-cell scheduling, the following principles should be taken into account:* * *The multi-cell scheduling grant is for unicast DL scheduling only or unicast UL scheduling only.* * *The scheduled cells can be associated with the same/different TDD configurations/numerologies.* * *Either Pcell or a Scell can be configured as a scheduling cell for joint multi-cell scheduling.* * *For a scheduled cell, there is only one scheduling cell.* * *The scheduled PDSCHs or PUSCHs correspond to different TBs.* * *Changes or extensions to the legacy PDCCH coding/mapping procedure, including the maximum DCI size=140 bits excluding CRC and supported ALs, should be avoided.* * *The number of cells that can be scheduled by a single DCI is no larger than 8 and is configurable.* * **CATT** * *Proposal 6: At least the case that the same SCS configuration among multiple scheduled cells should be supported firstly. Whether to support different SCS configuration among multiple scheduled cells can be further studied.* * **China Telecom** * *Proposal 1: Support UL cell configured with SUL for multi-cell PUSCH scheduling with a single DCI.* * *RAN1 needs to clarify whether both only one UL cell and multiple UL CA cells configured with SUL are the supported scenarios for multi-cell scheduling.* * **Lenovo** * *Proposal 1: Multi-cell scheduling considers two cases: (1) one PDSCH or PUSCH is self-scheduled and other PDSCHs or PUSCHs are cross-carrier scheduled; (2) all the PDSCHs or PUSCHs are cross-carrier scheduled.* * *Proposal 2: Multi-cell scheduling DCI can schedule multiple unlicensed carriers with or without licensed carriers.* * *Proposal 3: A multi-cell scheduling DCI schedules different TBs on different carriers.* * **Xiaomi** * *Proposal 7: DL/UL transmission cannot be scheduled simultaneously by a single DCI.* * **Samsung** * *Proposal 1: Prioritize the intra-band, collocated CA scenario in the multi-cell scheduling designs, while considering inter-band or non-collated CA as well.* * **InterDigital** * *Proposal 4: RAN1 to agree on at least one baseline scenario for the set of schedulable carriers and their bandwidths.* * **NTT DOCOMO** * *Proposal 3: Separate TB is scheduled for each cell by the single DCI scheduling multi-cell PDSCH/PUSCH.* * *Proposal 4: Either PDSCHs or PUSCHs on multiple cells are scheduled with a single DCI.* * *Proposal 5: Multi-cell PDSCH/PUSCH scheduling targets to support at least following scenarios;* * *Scheduling cell and scheduled cells are within a same band or in different bands with same numerology* * *FFS: different numerologies, with potentially updating WID to allow “multiple PDSCHs/PUSCHs per cell”*   + - *case 1: between scheduling and scheduled cells (same numerology across scheduled cells)*     - *case 2: across scheduled cells* * *Proposal 13: For multi-carrier scheduling with a single DCI, the following scenarios need further investigation on additional specification impacts/standardization effort.* * *whether FR2-2 can be supported for a scheduling cell and for scheduled cell(s)* * *whether the cell with shared spectrum operation can be scheduling cell for the multi-carrier scheduling* * *whether scheduled cells can include both cells with and without shared spectrum operation simultaneously* * *whether SCell can be a scheduling cell for multi-carrier scheduling of multiple scheduled cells including P(S)Cell* * **Intel** * *Proposal 2* * *Joint scheduling of cells in intra-band, inter-band CA scenario and in FR1 and FR2 for multi-cell scheduling is supported.* * *Joint scheduling of cells in licensed and unlicensed bands for multi-cell scheduling is not supported.* * *Proposal 5* * *Repetition is not supported if more than one PDSCHs or PUSCHs are scheduled for multi-cell scheduling.* * **Ericsson** * *Proposal 2: At least the case where all PUSCH/PDSCH scheduled by a mc-DCI have same SCS is supported.* * **Qualcomm** * *Proposal 1:* * *Consider following as design target scenarios for multi-cell scheduling with a single DCI*   + - *Scenario 1: Multiple cells with narrow bandwidth(s) (e.g., 5 and/or 10MHz) across FR1 bands*       * + *The cells belong to the same carrier type (e.g., FR1-FDD) with the same numerology*     - *Scenario 2: Multiple cells with wide bandwidth (e.g., 100MHz) within a band*       * + *The cells belong to the same carrier type (e.g., FR2/Unlicensed) with the same numerology*     - *For both scenarios, scheduling cell can be one of, or, none of the scheduled cells*       * + *If the scheduling cell is none of the scheduled cells, the scheduling cell and the scheduled cells can belong to different carrier types and/or can have different numerologies* * *Specification supports multi-cell scheduling by a single DCI of up to [4 or 8] cells* * *Proposal 2:* * *Prioritize both spectral and power efficiency enhancements for CA with multi-cell scheduling with a single DCI* * *With respect to power efficiency enhancements, specify solutions to enable a UE to adapt the bandwidth(s) for operation with multiple cells* * *Proposal 3:* * *In this WI, do not change the following existing CA framework*   + - *A transport block does not span multiple cells*     - *HARQ processes are independent for different cells*     - *SCell activation/deactivation and SCell dormant BWP is per cell*     - *PUCCH is transmitted on only one cell and UCI multiplexing on PUSCH is only one PUSCH among all the overlapped PUSCHs (if any)*     - *Scheduled cells and scheduling cell are in the same cell-group or PUCCH-group*     - *A DCI can schedule either PDSCH(s) or PUSCH(s) (not both)* * *A DCI format for multi-cell scheduling is configured to be monitored on USS set(s) and the DCI format is a non-fallback DCI format*   + *I.e., CSS set(s) and fallback DCI format(s) do not support multi-cell scheduling* |

## Moderator summary and proposals based on contributions

Based on contributions submitted by companies, below issues are prioritized for discussion in this meeting. Within each sub-section, the summary from moderator’s perspective is listed and followed by draft proposals for further discussion round by round.

For convenience of discussion, two DCI formats, DCI format 0-X and DCI format 1-X, can be used for time being only for discussion purpose, wherein DCI format 0-X is used for scheduling multiple PUSCHs on multiple serving cells with one PUSCH per serving cell and DCI format 1-X is used for scheduling multiple PDSCHs on multiple serving cells with one PDSCH per serving cell. The final naming in standards is up to editors.

According to WID, one issue needs to be clarified is whether the multiple PDSCHs or PUSCHs scheduled by a single DCI can carry a single TB with repetitions or different TBs on different carriers. For high data rate purpose, different TBs should be transmitted on different carriers. For reliability improvement purpose, one TB can be repeated on multiple carriers scheduled via a single DCI. Considering existing HARQ entities are maintained per serving cell, TB repetition on multiple serving cells inevitably leads to significant standard impact on RAN2.

Regarding TBs transmitted on co-scheduled serving cells, five companies [ZTE, Lenovo, NTT DOCOMO, vivo, Intel] propose separate TBs are scheduled on multiple serving cells by the multi-cell scheduling DCI. Hence, it is necessary to make it clearer with an agreement, e.g., a multi-cell scheduling DCI schedules different TBs on different carriers.

Regarding whether to adopt fallback DCI for multi-cell scheduling, three companies [NTT DOCOMO, Lenovo, Qualcomm] propose multi-cell scheduling is not supported for fallback DCI considering multi-cell scheduling DCI has large payload size and many fields are configurable based on RRC configuration. It is ok to make it clearer with an agreement although it is obvious.

Regarding search space set for monitoring multi-cell scheduling DCI, two companies [NTT DOCOMO, Qualcomm] propose that only USS set should be the applicable search space type for multi-carrier PDSCH/PUSCH scheduling DCI. This is because the motivation for supporting multi-carrier scheduling is to increase the flexibility and spectral/power efficiency for DL/UL data scheduling by reducing the control overhead. A simple agreement can be made as baseline framework.

For DCI payload size reduction, 7 companies [Nokia, Spreadtrum, vivo, Lenovo, OPPO, Apple, Qualcomm] propose the co-scheduled carriers should be within same cell group so that HARQ-ACK feedback corresponding to the co-scheduled carriers can be included in a same HARQ-ACK codebook. In this way, single DAI, single HARQ-ACK feedback timing indicator, single PUCCH resource indicator as well as single TPC command can be indicated in the DCI and shared/common for all the co-scheduled carriers, which can save DCI overhead without impact on system performance.

To make it clear that the multi-cell scheduling DCI does not support simultaneous scheduling of DL and UL with a single DCI due to significant standard impacts, moderator suggests focussing on the scenario that either PDSCHs or PUSCHs are scheduled with a single DCI in this WI.

As specified in Rel-17 due to introduction of FR2-2, the number of subcarrier spacing values is increased to 7. The SCS has impact on DCI format design and UE processing time. Considering the processing timeline for decoding/preparing control/data for different numerologies can be widely varying, high complexity will be caused if too many different subcarrier spacings are used for co-scheduled cells by a single multi-cell DCI. 5 companies [Huawei, Nokia, CATT, NTT DOCOMO, Ericsson] propose prioritizing same SCS among scheduled cells firstly and FFS different SCS cases. Moderator suggests trying this proposal first for this meeting.

For multi-cell scheduling in case of intra-band CA, it is natural to benefit from the PDCCH overhead reduction by using multi-cell scheduling DCI to schedule PUSCH/PDSCH on the scheduling cell. Therefore, a simple conclusion is required to make it clear.

In Rel-17, cross-carrier scheduling from SCell to PCell is specified. It needs to discuss whether an SCell can be a scheduling cell for multi-cell scheduling multiple scheduled cells including PCell, e.g., PDCCH on SCell schedules multiple PDSCHs/PUSCHs on PCell and one or more SCell(s).

### 1st round of discussions

#### Proposal 1-1:

* Agree the following terminologies only for convenience of discussion:
* DCI format 0-X is used for scheduling multiple PUSCHs on multiple serving cells with one PUSCH per serving cell
* DCI format 1-X is used for scheduling multiple PDSCHs on multiple serving cells with one PDSCH per serving cell.

#### Proposal 1-2:

* Different TBs are scheduled on different PUSCHs by DCI format 0-X.
* Different TBs are scheduled on different PDSCHs by DCI format 1-X.

#### Proposal 1-3:

* Fallback DCI (i.e., DCI formats 0\_0 and 1\_0) does not support multi-cell scheduling.

#### Proposal 1-4:

* The DCI for multi-cell scheduling is monitored only in USS set.

#### Proposal 1-5:

* PDSCH cannot be scheduled by DCI format 0\_X.
* PUSCH cannot be scheduled by DCI format 1\_X.

#### Proposal 1-6:

* All the cells scheduled by a DCI format 1-X are included in same cell group.

#### Proposal 1-7:

* At least support same SCS configuration among co-scheduled cells for multi-cell scheduling.
* FFS: Whether to support different SCS configurations between co-scheduled cells and the scheduling cell in case of same SCS for co-scheduled cells
* FFS: Whether to support different SCS configurations among co-scheduled cells
* FFS: Whether to support different carrier types (e.g., FDD+TDD, licensed + unlicensed) among co-scheduled cells

#### Proposal 1-8:

* DCI format 0-X/1-X on a scheduling cell can be used to schedule PUSCH/PDSCH on that scheduling cell.

#### Proposal 1-9:

* DCI format 0-X/1-X can be transmitted on PCell or SCell.
* FFS whether a DCI format 0-X/1-X on an SCell can schedule multiple cells including PCell.

Companies are encouraged to provide comments in the table below.

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| **Company** | **Comment** |
| Spreadtrum | For Proposal 1-6, we propose to change it into PUCCH group. Since there are can be up to two PUCCH groups in a cell group. However, HARQ-ACK codebook for PDSCHs and UCI multiplexing on PUSCH are both defined within the PUCCH group. Thus, for simplicity, HARQ-ACK feedback for PDSCHs scheduled by multi-cell DCI would be good limited within a PUCCH group, instead of cell group. Proposal 1-6 (update):  * All the cells scheduled by a DCI format 1-X are included in same PUCCH group. |
| Qualcomm | P1-1: OK  P1-2:  We propose to re-formulate it as follows since we have not yet concluded whether/how to support PDSCH or PUSCH repetition in a carrier.   * Different TBs are scheduled on different carriers ~~PUSCHs~~ by DCI format 0-X. * Different TBs are scheduled on different carriers ~~PDSCHs~~ by DCI format 1-X.   P1-3: OK  P1-4: OK  P1-5: OK  P1-6:  We propose to reformulate it as follows. Scheduling cell and scheduled cells should be in the same cell-group or PUCCH-group.   * All the scheduled cells and the scheduling cell for multi-cell PDSCH scheduling ~~scheduled~~ by a DCI format 1-X are included in same cell group or PUCCH-group. * All the scheduled cells and the scheduling cell for multi-cell PUSCH scheduling by a DCI format 0-X are included in same cell group.   P1-7:  We propose to re-formulate it as follows. First of all, the “co-scheduled cells” must mean the cells scheduled by a same DCI format 0-X/1-X, which should be clear.  Then we propose to delete “FFS” on the first subbullet. We think this is important to enable FR1-FR2 CA. We do not see any additional impact from this on most of the aspects (e.g., DCI format design). The only necessary thing is to ensure the time gap between the PDCCH and PDSCH/PUSCH – however, this is already in the spec for cross-carrier scheduling with different numerologies and hence the additional impact must be minor.   * At least support same SCS configuration among co-scheduled cells for multi-cell scheduling by a DCI format 0-X/1-X. * ~~FFS: Whether to s~~Support different SCS configurations between co-scheduled cells and the scheduling cell in case of same SCS for co-scheduled cells * FFS: Whether to support different SCS configurations among co-scheduled cells * FFS: Whether to support different carrier types (e.g., FDD+TDD, licensed + unlicensed) among co-scheduled cells   P1-8:  We propose to re-formulate it as follows.   * DCI format 0-X/1-X on a scheduling cell can be used to schedule PUSCHs/PDSCHs on multiple cells that include the scheduling cell. * DCI format 0-X/1-X on a scheduling cell can be used to schedule PUSCHs/PDSCHs on multiple cells that do not include the scheduling cell.   P1-9: OK |
| Nokia/NSB | We support all the proposals.  Related to proposal 1-6, we are wondering if the MC-DCI PUSCH scheduling using 0\_X should also be limited within the same (PUCCH) cell group. |
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# DCI format design

Based on contributions submitted by companies, below issues are prioritized for discussion in this meeting. Within each sub-section, the summary from moderator’s perspective is listed and followed by draft proposals for further discussion round by round.

## Maximum number of cells scheduled by a single DCI

Regarding this issue, companies’ views are summarized as below:

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| * **Huawei, HiSilicon** * *Proposal 2: The scenario that 2 and 3 cells scheduled simultaneously by a single DCI can be prioritized.* * *Proposal 3: The actual number of cells which could be scheduled simultaneously by a single DCI can be smaller than the maximum number of cells which could be scheduled simultaneously by a single DCI.* * **ZTE** * *Proposal 2: 4 or 8 should be supported as the maximum number of scheduled cells.* * **Nokia, Nokia Shanghai Bell** * *Proposal 3.3.2: Support a maximum of 4 cells that can be scheduled simultaneously by a single DCI.* * *Proposal 3.3.3: To limit the DCI size, the maximum number of cells that can be scheduled should be based on RRC configuration (i.e. from the set of {2,3,4}).* * *Proposal 3.3.4: Support separate configurations for the multi-cell scheduling DCI for PDSCH and PUSCH* * **Spreadtrum Communications** * *Proposal 5: At least Support up to 4 cells scheduling with a single DCI.* * **Vivo:** * Proposal 1. For multi-cell scheduling, the following principles should be taken into account: * *The multi-cell scheduling grant is for unicast DL scheduling only or unicast UL scheduling only.* * *The scheduled cells can be associated with the same/different TDD configurations/numerologies.* * *Either Pcell or a Scell can be configured as a scheduling cell for joint multi-cell scheduling.* * *For a scheduled cell, there is only one scheduling cell.* * *The scheduled PDSCHs or PUSCHs correspond to different TBs.* * *Changes or extensions to the legacy PDCCH coding/mapping procedure, including the maximum DCI size=140 bits excluding CRC and supported ALs, should be avoided.* * *The number of cells that can be scheduled by a single DCI is no larger than 8 and is configurable.* * **CATT** * *Proposal 1: The maximum number of cells that can be scheduled by a single should be no more than 4 Cells with each TB scheduled per cell.* * *Proposal 2: There are two options on the actual number of scheduled cells by a DCI as follows.* * *Option-1: is fixed to N, the scheduled cells are configured by higher layer.* * *Option-2: can dynamically change from 1 to M, the combination of scheduled cells is indicated by DCI, e.g. carrier indicator field.* * **China Telecom** * *Proposal 6: The maximum number of cells that can be scheduled simultaneously should not lead to the increasing of maximum DCI size supported by polar code.* * **NEC** * *Proposal 1: The maximum number of cells that can be scheduled simultaneously is 4.* * **Lenovo** * *Proposal 4: The maximum number of carriers which can be scheduled by a single DCI is 4.* * *Proposal 5: For a given DCI format, the maximum number of carriers which can be scheduled by the DCI is configured by RRC signaling from a set of possible values of 2, 3 and 4.* * **Xiaomi** * *Proposal 1: The maximum number of cells which can be scheduled by a single DCI is 3.* * *Proposal 2: The number of scheduled cells can be dynamically indicated by the scheduling DCI.* * **OPPO** * *Proposal 1: The maximum number of cells scheduled simultaneously is configurable.* * *The configured “maximum number” is not larger than 4.* * *The configured “maximum number” is subject to reported UE capability.* * *Proposal 2: If the maximum number of cells scheduled simultaneously is configured as M,* * *The DCI format used for multi-cell scheduling has its field length and total size determined by value of M.* * *The DCI format used for multi-cell scheduling could actually schedule N cells simultaneously for N≤M, with the unused payload corresponding to (M-N)-cell scheduling filled with padding.* * **InterDigital** * *Proposal 5: The maximum number of simultaneously scheduled cells is not lower than 4.* * **CAICT** * *Proposal 2: The maximum number of cells to be simultaneously scheduled by a single DCI is configurable.* * **Apple** * *Proposal 1: RAN1 specifications support a maximum of 3 or 4 cells (FFS 3 or 4) that can be scheduled simultaneously by a single DCI for both PDSCH and PUSCH.* * *The actual maximum of cells scheduled by a single DCI should depend on UE capability and the band/band combinations.* * **NTT DOCOMO** * *Proposal 6: Discuss following alternatives for the target maximum number of scheduled cells;* * *Alt.1: 8* * *Alt.2: 6* * *Alt.3: 4* * *Note1: Following aspects should be considered to specify the maximum number of scheduled cells: DCI size limitation, DCI compression gain by multi-carrier scheduling by single DCI, PDCCH blocking rate, practical use-case.* * *Note2: UE is configured with a certain number of potential scheduled cells (equal to or less than above value), and UE capability for maximum number of scheduled cells may be considered.* * **LG Electronics** * *Proposal #3: Discuss how to limit DCI payload size of the multi-cell DCI, based on the following considerations.* * *The maximum number of simultaneously scheduled cells is to be limited to X (e.g. X = 4).* * *The maximum number of simultaneously scheduled TBs is to be limited to Y (e.g. Y = 4).* * **MediaTek** * *Proposal 1: For R18 multi-cell PUSCH/PDSCH scheduling with a single DCI, RAN1 aims to support* the maximum number of cells that can be scheduled simultaneously to be 4, or more. * **Intel** * *Proposal 1* * *Maximum number of cells for multi-cell scheduling can be 8.* * **Ericsson** * *Proposal 1: Maximum number of cells scheduled by a mc-DCI is selected from {4,8}.* |

### Moderator summary and proposals based on contributions

Compared to single PDSCH scheduling, the DCI overhead for multi-cell scheduling is rapidly increased with the number of co-scheduled carriers. According to WID, clearly the number of co-scheduled carriers should be at least 3 so it does make sense that the maximum number of schedulable carriers can be 4, 6 or 8. However, in the existing standards, the maximum size of DCI in the Polar code is 140bits excluding 24-bit CRC. Determining the maximum number of schedulable carriers by a single DCI should consider both the limitation of 140bits for Polar coding and scheduling flexibility as well as the probability of scheduling a large number of carriers.

Regarding maximum number of schedulable carriers by a single DCI, below companies express clear views on the max number:

* **Maximum number of schedulable carriers by a single DCI is 4.**
* *Supported by Nokia/NSB, Spreadtrum, CATT, NEC, Lenovo, OPPO, LG*
* **Maximum number of schedulable carriers by a single DCI is 8.**
* *Supported by vivo, Intel*
* **Maximum number of schedulable carriers by a single DCI is 3.**
* *Supported by Xiaomi*

In addition, two companies [ZTE, Ericsson] support 4 or 8 as the maximum schedulable carrier number. One company [Apple] propose FFS 3 or 4. One company [InterDigital] propose the maximum number is not lower than 4. One company [NTT DOCOMO] propose FFS 8, 6 or 4. One company [MediaTek] propose 4 or more.

It is obvious that majority companies prefer maximum 4 schedulable carrier. Moderator suggests maximum 4 schedulable carriers by a single DCI in the first round of discussions. If not agreeable, then we can agree the maximum schedulable carrier number is down-selected from {4 or 8}.

Assuming N is the maximum number of cells supported in standards, it does not mean that always N serving cells are scheduled by the multi-cell scheduling DCI considering the traffic and CA capability of UE. Therefore, it is true the actual maximum number of schedulable cells can be dependent on gNB configuration, e.g., for a UE, maximum M cells can be scheduled by a multi-cell DCI, M<=N. The actual number of scheduled carriers may be smaller than M.

Moreover, considering different CA capabilities and transmission power for DL and UL for a UE, the configuration for multi-cell scheduling DCI can be different for DL and UL.

### 1st round of discussions

#### Proposal 2-1:

* The maximum number of cells scheduled by a DCI format 0-X in Rel-18 standards is 4.
* For a UE, the maximum number of cells scheduled by a DCI format 0-X can be smaller than 4.

#### Proposal 2-2:

* The maximum number of cells scheduled by a DCI format 1-X in Rel-18 standards is 4.
* For a UE, the maximum number of cells scheduled by a DCI format 1-X can be smaller than 4.

#### Proposal 2-3:

* For a UE, the maximum number of cells scheduled by a DCI format 0-X is separately configured from the maximum number of cells scheduled by a DCI format 1-X.

Companies are encouraged to provide comments in the table below.

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| **Company** | **Comment** |
| Qualcomm | P2-1:  We think working assumption would be better on the maximum number of cells that can be scheduled by a DCI format 0-X for the purpose of further discussion of DCI format design. It is premature to conclude/fix the value without any analysis/discussion. We think we can go with the number “4” as working assumption.  P2-2:  We think working assumption would be better on the maximum number of cells that can be scheduled by a DCI format 1-X for the purpose of further discussion of DCI format design. It is premature to conclude/fix the value without any analysis/discussion. We think we can go with the number “4” as working assumption.  P2-3:  The proposal is not clear. Our understanding is as follows.   * A UE can be configured with one or multiple sets of cells where each set can be scheduled by a DCI format 0-X.   + Within each set, the actual data scheduling by the DCI format 0-X can be for a subset of cells. * A UE can be configured with one or multiple sets of cells where each set can be scheduled by a DCI format 1-X.   + Within each set, the actual data scheduling by the DCI format 1-X can be for a subset of cells. |
| Nokia/NSB | We support all 3 proposals. |
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## Scheduling possibilities

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| * **Nokia, Nokia Shanghai Bell** * *Proposal 3.2.1: Each scheduled cell can be configured to be scheduled by a multi-cell DCI in one and only one scheduling cell.* * *Proposal 3.2.3: For a scheduled cell,*    + *support multi-cell DCI and single-cell DCI scheduling from one scheduling cell*   + *support multi-cell DCI scheduling from one scheduling cell and single-cell DCI self-scheduling*   + *do not support multi-cell DCI and single-cell DCI cross-carrier scheduling from more than one (other) scheduling cell.* * *Proposal 3.3.6: Support the monitoring for at least two multi-cell DCIs for PDSCH (or PUSCH) on different scheduling cells within a PUCCH cell group, where each of the multi-cell DCIs can schedule a different (non-overlapping) subgroup of cells within a PUCCH cell group.* * **Spreadtrum Communications** * *Proposal 6: At least support Case 0 multi-cell scheduling, i.e one Cell’s scheduling only from multi-cell scheduling, not configured as self-carrier nor cross-carrier scheduling* * *Proposal 7: Further study the other type of multi-cell scheduling, e.g. combination of self/cross-carrier scheduling.* * *Proposal 8: It is recommended to give a restriction for the maximum number of scheduling cells when multi-carrier scheduling is configured for a scheduled cell.* * **Vivo** * *Proposal 1. For multi-cell scheduling, the following principles should be taken into account:* * *The multi-cell scheduling grant is for unicast DL scheduling only or unicast UL scheduling only.* * *The scheduled cells can be associated with the same/different TDD configurations/numerologies.* * *Either Pcell or a Scell can be configured as a scheduling cell for joint multi-cell scheduling.* * *For a scheduled cell, there is only one scheduling cell.* * *The scheduled PDSCHs or PUSCHs correspond to different TBs.* * *Changes or extensions to the legacy PDCCH coding/mapping procedure, including the maximum DCI size=140 bits excluding CRC and supported ALs, should be avoided.* * *The number of cells that can be scheduled by a single DCI is no larger than 8 and is configurable.* * *Proposal 2. For a scheduled cell, both multi-cell scheduling and single-cell scheduling can be configured at the same time.* * **China Telecom** * *Proposal 4: The cell(s) to transmit the multi-cell scheduling DCI are configured by RRC signaling.* * *Proposal 5: Multi-cell scheduling and single-cell scheduling can be dynamically switched for a cell supporting multi-cell scheduling DCI.* * **LG Electronics** * *Proposal #4: Discuss how to support multi-cell scheduling and single-cell monitoring in case with the multi-cell DCI, based on the following three approaches.* * *Approach 1: The multi-cell DCI is allowed to perform single-cell scheduling for any of the cells schedulable by the multi-cell DCI.* * *Approach 2: The multi-cell DCI is not allowed to perform single-cell scheduling for any of the cells schedulable by the multi-cell DCI.* * *Approach 3: The multi-cell DCI is allowed to perform single-cell scheduling only for the scheduling cell (while not allowed for other cells).* * **Ericsson** * *Proposal 3: mc-DCI on a scheduling cell can be used to schedule PUSCH/PDSCH on that scheduling cell, at least when all cells have same SCS.* * *Proposal 4: When mc-DCI is configured for scheduling PUSCH/PDSCH on multiple cells, a mc-DCI can schedule PUSCH/PDSCH on all of the cells or a subset of those cell (including single cell).* * *Proposal 5: When mc-DCI is configured for scheduling PUSCH/PDSCH on multiple cells, for each of those cells, UE can also be configured to monitor existing single cell DCI format(s) scheduling PUSCH/PDSCH (i.e. 1\_1/1\_2/0\_1/0\_2).* * *Proposal 6: When mc-DCI is configured for scheduling PUSCH/PDSCH on multiple cells, existing Rel-17 DCI size budget is maintained for each scheduled cell.* * *Proposal 7: Size of mc-DCI is explicitly configured by higher layers.* * *Proposal 8: Support independent configuration of mc-DCI for PUSCH and PDSCH.* * **FGI** * *Proposal 3: Support self-scheduling for a DCI scheduling multiple cells.* * *Proposal 4: Support monitoring in a SCell for a DCI scheduling multiple cells.* * *Proposal 5: Support monitoring in a sSCell for a DCI scheduling multiple cells including PCell.* |

### Moderator summary and proposals based on contributions

Regarding scheduling possibilities for multi-cell scheduling and possible single-cell scheduling, several issues need to be considered.

A first issue is whether there is only one scheduling cell for a scheduled cell. In Rel-15/16, there is only one scheduling cell for each serving cell by self-scheduling or cross-carrier scheduling. In Rel-17, a sScell can be configured to cross-carrier schedule PCell in addition to PCell self-scheduling so that PCell can have two scheduling cells. For Rel-18 multi-cell scheduling, it could be easier if the principle that there is only one scheduling cell for each scheduled cell can be maintained.

However, if multi-cell DCI scheduling and single-cell DCI scheduling are only from the same scheduling cell, this would lead to high DL control load on the scheduling cell as both multi-cell scheduling DCI and single-cell scheduling DCI are transmitted from same scheduling cell for multiple scheduled cells. In this way, it is beneficial if multi-cell DCI scheduling from one scheduling cell and single cell scheduling from the scheduled cell via self-scheduling can be supported.

A second issue is whether UE can be configured to monitor multiple multi-cell scheduling DCIs on multiple scheduling cells. This would add to the network DCI loading flexibility but is likely adding more UE side implementation burden and add to the blind decoding budget management complexity. Therefore, at most one serving cell can be configured for monitoring multi-cell scheduling DCI for a scheduled cell.

### 1st round of discussions

#### Proposal 2-4:

* For each scheduled cell, at most one scheduling cell can be configured for a UE to monitor multi-cell scheduling DCI.

#### Proposal 2-5:

* For a scheduled cell, both multi-cell scheduling and single cell scheduling can be supported from a same scheduling cell.
* FFS whether there is at most one scheduling cell for each scheduled cell.
* FFS whether to support multi-cell scheduling from one scheduling cell and single cell scheduling from the scheduled cell via self-scheduling.
* FFS whether to support multi-cell scheduling from one scheduling cell and single cell scheduling from another scheduling cell for the scheduled cell via cross-carrier scheduling.

Companies are encouraged to provide comments in the table below.

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| **Company** | **Comment** |
| Spreadtrum | For Proposal 2-4, it needs a clarification, that not all serving cell support multi-cell scheduling, so it would be good change into “For each scheduled cell applicable for multi-cell scheduling ” |
| Qualcomm | P2-4: We are not OK.  For CA with different numerologies (e.g., FR1-FR2 CA), monitoring DCI 0-X/1-X on a FR1 cell that can schedule FR2 cells is a potential power efficient operation.  However, due to the SCS/slot-length difference between the FR1 scheduling cell and the FR2 scheduled cells, if the scheduling cell is fixed to the FR1 cell, the UE has to be able to (1) process multiple DCIs in a PDCCH MO of the FR1 cell, or (2) monitor multiple PDCCH MOs of a slot of the FR1 cell. One option could be to enable “scheduling cell switch” dynamically. We consider this could be a potential resolution for other issues such as DCI size budget, BD/CCE budget, HARQ re-transmission flexibility, etc.      P2-5: We are not OK.  Not clear but the proposal looks implying that, if a UE is configured with 1-to-N multi-cell scheduling, the UE has to be able to support 1-to-N cross-carrier scheduling altogether. When N=4, on the scheduling cell(s), the UE monitors DCI format 0-X/1-X for the N=4 cells and also monitors DCI formats 1\_1/0\_1 with CIF for all the N=4 cells. This is extremely high cost from UE’s PDCCH process capability point of view.  We are open to discuss a certain way of switching as illustrated above. It should be clear whether P2-5 means the UE has to support simultaneous monitoring MC-DCI and SC-DCI. |
| Nokia/NSB | We support the 2 proposals above. |
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## New or existing DCI format for multi-cell scheduling

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| * **Huawei, HiSilicon** * *Proposal 5: Introduce new DCI formats for multi-cell scheduling by single DCI for DL and UL respectively.* * *Proposal 6: Legacy DCI formats for PDSCH/PUSCH scheduling and new DCI formats for multi-cell PDSCH/PUSCH scheduling can be monitored simultaneously.* * **ZTE** * *Proposal 6: Whether using legacy non-fallback DCI formats or new DCI formats for multi-cell scheduling should be down-selected.* * **Nokia, Nokia Shanghai Bell** * *Proposal 3.1: Introduce new DCI formats 0\_X (e.g. 0\_3) for multi-cell PUSCH scheduling with a single DCI and 1\_X (e.g. 1\_3) for multi-cell PDSCH scheduling with a single DCI.* * *Proposal 3.2.2: Support the combination of multi-cell DCI scheduling and single-cell DCI scheduling (using legacy DCI formats) for PDSCH (or PUSCH) of a serving cell.* * **CATT** * *Proposal 4: Whether to introduce a new DCI format for the DCI that can schedule multi-cells PDSCH/PUSCH need to be discussed until it is clear how to determine each configured field of the DCI.* * **Vivo** * *Proposal 5. Introduce new DCI format(s) for mc-DCI.* * **Xiaomi** * *Proposal 3: New DCI formats should be introduced to support multi-cell scheduling.* * *Proposal 4: The DCI supporting multi-cell scheduling can also be used for single cell scheduling.* * *Proposal 6: Single cell scheduling using legacy DCI and multi-cell scheduling can be enabled simultaneously.* * **Langbo** * *Proposal 3: New DCI formats are introduced respectively for multi-cell PUSCH scheduling and multi-cell PDSCH scheduling.* * **OPPO** * *Proposal 6：A new DCI format is needed to support multi-cell scheduling in a single DCI.* * *FFS: whether this new DCI format uses existing DCI format name or new DCI format name.* * **CMCC** * *Proposal 1. For one scheduled cell, both multi-cell PUSCH/PDSCH scheduling with a single DCI and legacy single cell PUSCH/PDSCH scheduling with a single DCI should be supported.* * **CAICT** * *Proposal 1: One cell could be scheduled by a legacy DCI or by a new DCI for multi-cell PUSCH/PDSCH scheduling. The new DCI for multi-cell PUSCH/PDSCH scheduling could also be used to schedule a single cell.* * **Apple** * *Proposal 6: The multi-cell scheduling DCI formats are designed based on DCI formats 0\_1 and 1\_1.* * *FFS whether to introduce new DCI formats or modify DCI formats 0\_1/1\_1, and potentially the handling of the limit on the number of DCI sizes* |

### Moderator summary and proposals based on contributions

Regarding the DCI format design for multi-cell PDSCH/PUSCH scheduling, reusing legacy DCI format, e.g., DCI format 0-1 or 1-1, can avoid extra blind detection effort for a UE since existing “3+1” DCI size budget is maintained. However, the drawback is there are too many carrier-specific fields which have to be left unused in case of same DCI format for single carrier scheduling and the more CCEs are required for transmitting the DCI format. Furthermore, the standard efforts for differentiating DCI format for multi-cell scheduling or single cell scheduling are needed.

On contrast, introducing new DCI format for multi-cell scheduling can provide a clean design for standards and gNB can flexibly adopt multi-cell scheduling or single cell scheduling dependent on actual scenarios. However, with the introduction of the new DCI format for multi-cell scheduling and the legacy DCI format for single cell scheduling, “3+1” DCI size budget may not be maintained since UE has to monitor DCI formats for single cell scheduling, DCI formats for multi-cell scheduling and one fallback DCI format. Extra standard effort is needed to keep existing “3+1” DCI size budget.

8 companies [Huawei, ZTE, Nokia/NSB, CATT, vivo, Lenovo, Xiaomi, Langbo, OPPO, CAICT] propose new DCI format for multi-cell scheduling by a single DCI. Two companies [ZTE, CATT] propose FFS whether introducing new DCI format or reusing legacy DCI format until each DCI field is clear.

Furthermore, if new DCI format is introduced for multi-cell scheduling, one follow-up issue is whether this multi-cell scheduling DCI can be used for single cell scheduling. As mentioned above, when the multi-cell scheduling DCI is used for scheduling a single cell, too many cell-specific bits have to be reserved. It does make sense that the multi-cell scheduling DCI is only used for scheduling two or more serving cells.

Another follow-up issue needs to be resolved is whether for one scheduled cell, both multi-cell scheduling DCI and legacy single cell scheduling DCI should be supported.

### 1st round of discussions

#### Proposal 2-6:

* New DCI formats are introduced for multi-cell PUSCH/PDSCH scheduling by single DCI for UL and DL respectively.
* The new DCI formats are not used for single cell PUSCH/PDSCH scheduling.
* Note: Legacy DCI formats are used for single cell PUSCH/PDSCH scheduling.
* UE can be configured to monitor both multi-cell scheduling DCI and legacy single cell scheduling DCI for a scheduled cell.

Companies are encouraged to provide comments in the table below.

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| **Company** | **Comment** |
| Qualcomm | P2-6:  For the 1st bullet, we can make it as a working assumption. It is not fruitful to discuss whether the DCI 0-X/1-X is a new format or a modification of a legacy format. Or alternatively, we do not need to determine it for now.  For the 2nd bullet, we are not OK with this proposal due to the same comment as for P2-5. If the intention of the proposal is to enable “fallback to legacy single-cell scheduling operation”, it should be clear for which condition(s) a UE is configured to monitor both multi-cell scheduling DCI and legacy single-cell scheduling DCI. For example, for legacy cross-carrier scheduling, the UE can monitor only DCI 1\_1/0\_1 with CIF for scheduled cells that is not the scheduling cell, and can monitor both DCI 1\_1/0\_1 with CIF and DCI 1\_0/0\_0 without CIF if the scheduled cell is the scheduling cell. We are open to discuss the need of such fallback mechanism. However, we cannot agree to support monitoring both DCIs simultaneously for all the scheduled cells in general. |
| Nokia/NSB | We support the main bullet of Proposal 2-6, but don’t think the restriction of the first sub-bullet is actually needed (should be removed from a potential agreement).  Could be left to gNB to still use the MC-DCI to schedule also only a single cell with the MC-DCI (if SC-DCI monitoring is not to be configured for a serving cell). |
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## DCI size and BD/CCE budget

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| * **Huawei, HiSilicon** * *Proposal 7: Existing “3+1” DCI size budget should be maintained.* * **ZTE** * *Proposal 7: It should be determined that BD/CCE of multi-cell scheduling DCI is counted in one scheduled cell only or each scheduled cell.* * **Nokia, Nokia Shanghai Bell** * *Proposal 3.4.2: The multi-cell DCI size(s) are not counted towards the DCI size budget (for DCI formats scrambled by C-RNTI) per serving cell and not considered in the related serving cell specific DCI size alignment procedure. Instead,* *the gNB will guarantee that across the K cells applicable for multi-cell DCI scheduling that the total budget of 3\*K DCI sizes is not exceeded.* * **Spreadtrum Communications** * *Proposal 9: For Case 0, the BD and CCE for the scheduled cell are calculated as the scheduling cell. For BD and CCE handling of Case 1 and 2, scaling factor in Rel-17 DSS can be used as a starting point* * **CATT** * *Proposal 5: On the premise that no new requirement of blind detection is introduced for multi-cells scheduling, the ‘3+1’budget of DCI format size should be maintained.* * **Vivo** * *Proposal 6. The mc-DCI should be counted as part of the BD budget of the scheduling cell instead of the BD budget of each scheduled cell.* * **Lenovo** * *Proposal 9: Existing “3+1” DCI size budget should be maintained when designing the DCI format for multi-cell scheduling in Rel-18 CA enhancement.* * **OPPO** * *Proposal 8: The procedure of DCI size alignment should be updated if necessary. Further discussion is needed.* * **Samsung** * *Proposal 7: Further discuss the “3+1” limit on UE budget for DCI sizes, including voiding the limit for the case of multi-cell scheduling.* * **Apple** * *Proposal 7: Study the handling of BD/CCE limit, and whether one cell can be scheduled by multiple cells.* * **NTT DOCOMO** * *Proposal 10: RAN1 should discuss the following aspects related to DCI design for multi-carrier PDSCH/PUSCH scheduling with a single DCI;* * *whether multi-cell scheduling DCI is supported by non-fallback DCI (0\_1/1\_1) or by new DCI* * *whether multi-cell scheduling DCI can also schedule single cell* * *whether DCI size budget (3+1) is maintained* * *Proposal 12: RAN1 should discuss the following aspects related to SS set configuration/monitoring capability and BD/CCE budget for multi-carrier PDSCH scheduling with a single DCI;* * *applicable PDCCH monitoring capability* * *BD/CCE budget for each cell* * *limitation on scheduling cell(s) for a scheduled cell* * **CMCC** * *Proposal 4. The DCI size of new multi-cell scheduling DCI format should be fixed regardless the number of cells it schedules each time.* * *Proposal 5. To maintain the restriction of DCI size budget for a serving cell when a new DCI size is introduced, the DCI size alignment can be performed only on one of the scheduled cells through network configuration or pre-defined rule.* * *Proposal 6. Multi-cell PUSCH/PDSCH scheduling with a single DCI should maintain the current PDCCH BD/CCE budget. The number of PDCCH candidates and non-overlapping CCEs corresponding to the new DCI format can be calculated only in one of the schedule cells.* * **Intel** * *Proposal 9* * *Single or multiple configurations for the DCI fields of the DCI format for multi-cell scheduling can be configured on the scheduling cell.* * *Single-cell scheduling may still be supported at least for a cell that cannot be scheduled by the DCI format for multi-cell scheduling.* * *Special handling on the DCI format for multi-cell scheduling is necessary for the DCI size budget and maximum number of BD/CCEs.* * **LG Electronics** * *Proposal #5: Discuss how to maintain the DCI size budget per cell in case with the multi-cell DCI, according to Approach 1/2/3.* * *Proposal #6**: Discuss how to configure the number of PDCCH candidates per AL for the multi-cell scheduling by single DCI, based on following three alternatives as a starting point.*   + *Alt 1: The number of PDCCH candidates per AL is configured for each scheduled cell schedulable by the multi-cell DCI.*   + *Alt 2: The number of PDCCH candidates per AL is configured for each combination of scheduled cells simultaneously schedulable by the multi-cell DCI.*   + *Alt 3: The number of PDCCH candidates per AL is configured for the multi-cell DCI itself without differentiating scheduled cells.* * **Ericsson** * *Proposal 6: When mc-DCI is configured for scheduling PUSCH/PDSCH on multiple cells, existing Rel-17 DCI size budget is maintained for each scheduled cell.* * *Proposal 7: Size of mc-DCI is explicitly configured by higher layers.* * *Proposal 8: Support independent configuration of mc-DCI for PUSCH and PDSCH.* * **Qualcomm:** * *Proposal 6: BD/CCE budget for each scheduled cell follows the legacy CA* * *If a UE monitors PDCCH candidates for a DCI that schedules data on up to a set of N cells, maximum numbers of BDs and non-overlapped CCEs for the DCI that schedules data on up to the set of N cells are capped by per-cell BD/CCE budget* * **FGI** * *Proposal 6: Discuss how to count the size of a DCI scheduling multiple cells towards the DCI size budgets.* * *Proposal 7: If a DCI scheduling multiple cells is defined as a new DCI format, the DCI size alignment procedure needs to be enhanced to take into account the new DCI format.* |

### Moderator summary and proposals based on contributions

Based on conclusion of section 3.3, if new DCI format is introduced for scheduling multiple cells and the legacy DCI format is used for scheduling single cell, existing “3+1” DCI size budget may not be maintained since UE has to monitor DCI format 1-1 or 0-1 for single cell PDSCH or PUSCH scheduling, DCI format 1-X or 0-X for multi-cell PDSCH or PUSCH scheduling, and one fallback DCI format.

In legacy design, BDs/CCEs are counted for each scheduled cell. For multi-cell scheduling DCI which can schedule multiple cells, one issue is which cell the BD/CCE of the multi-cell scheduling DCI is counted for. Furthermore, if one cell can be scheduled by more than one cell, e.g., self-scheduling and cross-carrier scheduled by a multi-cell DCI on another cell, whether/how to split the BD/CCE budget between the multiple cells should also be considered.

Regarding the DCI size budget, 5 companies [Huawei, CATT, Lenovo, Ericsson, Qualcomm] propose existing “3+1” DCI size budget should be maintained. One company [Nokia] propose the DCI size budget not counted per cell and gNB guarantees that across the K cells applicable for multi-cell DCI scheduling that the total budget of 3\*K DCI sizes is not exceeded. One company [CMCC] propose the DCI size alignment can be performed only on one of the scheduled cells through network configuration or pre-defined rule and BD/CCE budget corresponding to the new DCI format can be calculated only in one of the schedule cells. One company [vivo] propose the mc-DCI should be counted as part of the BD budget of the scheduling cell instead of the BD budget of each scheduled cell. One company [Samsung] propose further discussing the “3+1” limit on UE budget for DCI sizes, including voiding the limit for the case of multi-cell scheduling.

Since the companies’ views are quite diverse, moderator suggests discussing the high-level principle first whether to keep existing “3+1” DCI size budget per scheduled cell. Then we can discuss details as long as we make conclusion.

### 1st round of discussions

#### Proposal 2-7:

* Further study DCI size budget based on below options if new DCI format is introduced for multi-cell scheduling:
* Option 1: Existing DCI size budget is maintained per scheduled cell.
  + Alt 1-1: via DCI size alignment
  + Alt 1-2: via configured size for multi-cell scheduling DCI
* Option 2: Existing DCI size budget is not necessarily maintained per scheduled cell.
  + Alt 2-1: DCI size budget of multi-cell scheduling DCI is counted only in one scheduled cell.
  + Alt 2-2: DCI size budget of multi-cell scheduling DCI is not counted per serving cell and not considered in the related serving cell specific DCI size alignment procedure, e.g., for K co-scheduled cells, gNB guarantee the total budget of 3\*K DCI sizes is not exceeded.
  + Alt 2-3: voiding the “3+1” limit for multi-cell scheduling

Companies are encouraged to provide comments in the table below.

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| **Company** | **Comment** |
| Qualcomm | We support Option 1.  The size of the DCI format for multi-cell scheduling should be still within the “3+1” budget for each scheduled cell. We are not sure why “3+1” is not sufficient for a given scheduled cell.  For example, following should be the worst case example (if we conclude to agree 2nd bullet of P2-5):   * 1st size for C-RNTI => DCI 1\_0/0\_0 * 2nd size for C-RNTI => DCI 1\_1/0\_1 or DCI 1\_2/0\_2 * 3rd size for C-RNTI => DCI 0-X/1-X   This implies that the DCI 1\_2/0\_2 cannot have different size than DCI 1\_1/0\_1 when it is configured with DCI 0-X/1-X. However, we do not think this is a big deal. It is network’s choice either to use DCI for multi-cell scheduling, or DCI 1\_2/0\_2 that has different size than DCI 1\_1/0\_1. |
| Nokia/NSB | Agree with the intention, but the formulation may not be totally accurate for Option 1. Option 1 basically assumes that the MC-DCI size is considered for each scheduled cell – but this does not have anything to do with ‘mainining the DCI size budget per scheduled cell.  So would be better to change Option 1 description to:  Option 1: The MC-DCI size is considered for each of the scheduable cells and the existing DCI size budget is maintained per scheduled cell.   * + Alt 1-1: via DCI size alignment   + Alt 1-2: via configured size for multi-cell scheduling DCI   Having a configured MC-DCI size could also be applicable to Option 2 (so we think the alternatives for Option 2 may not need to be restricted for now). |
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#### Proposal 2-8:

* Further study BD/CCE budget for multi-cell scheduling DCI based on below options:
* Alt 1: follow legacy BD/CCE budget for each scheduled cell
* Alt 2: counted only in one scheduled cell
* Alt 3: scaled down to each of co-scheduled cell according to the number of co-scheduled cells
* Alt 4: counted as part of the scheduling cell instead of each scheduled cell

Companies are encouraged to provide comments in the table below.

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| **Company** | **Comment** |
| Qualcomm | P2-8:  We believe Alt.1 is not an alternative – this is a baseline/default to realize the feature with a reasonable UE implementation. |
| Nokia/NSB | The alternatives to be considered do not need to be restricted now (… also additional alternatives could be still considered). |
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## Single or two-stage DCI

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| * **China Telecom** * *Proposal 7: For the multi-cell scheduling DCI, both options are considered and evaluated by RAN1:* * *Option 1: The bit number of the multi-cell scheduling DCI is semi-statically determined, dedicated fields are mapped to the RRC configured cells that can be scheduled by the DCI.* * *Option 2: There are two stages of the multi-cell scheduling DCI when multiple cells are scheduled, and the bit number of the second stage DCI scales with the actually scheduled cells.* * **InterDigital** * *Proposal 3: Support two-stage DCI for multi-cell scheduling where the scheduling information are carried using two DCIs.* * **MediaTek** * *Proposal 2: RAN1 to adopt a 2-segment DCI structure (as shown in Figure 2(c)) to support R18 multi-cell PUSCH/PDSCH scheduling with a single DCI.* * *Proposal 4: For the 2-segment aggregated DCI, the 1st and 2nd segment DCI are decoded separately on the same scheduling cell. The 1st and 2nd segment DCI are then linked together to form one multi-cell scheduling DCI. The link procedure of 1st and 2nd segment DCI can be based on some designated DCI bit values of the 1st or 2nd segment DCI* * *The linked 1st segment and 2nd segment DCI should be “both DL scheduling DCIs” or “both UL scheduling DCIs”* * **Samsung**   *Proposal 4: For a multi-cell scheduling DCI format, further consider the following three mechanisms:*   1. *single ‘concatenated’ DCI format in a PDCCH;* 2. *DCI format for multi-cell scheduling multiplexed in a PDSCH (a.k.a., two-stage DCI with 2nd stage on a PDSCH);* 3. *two-stage DCI on linked PDCCHs.* |

### Moderator summary and proposals based on contributions

Regarding the multi-cell scheduling DCI, 4 companies [China Telecom, MediaTek, InterDigital, Samsung] propose support/study of two-stage DCI, where the first stage DCI contains the scheduled cell indicator, common fields for multiple scheduled cells, scheduling information bits for second stage DCI. The scheduling information bits for second stage DCI indicates the time frequency resource used by the second stage DCI. The second stage DCI contains dedicated fields for the actually scheduled cells, which has a dynamically changed size but does not need blind detection. Since the second stage DCI is multiplexed in a PDSCH or a linked PDCCH, there is little constraint in terms of the size of the first-stage DCI. Therefore, the two stage DCI design can avoid additional effort on DCI size alignment as existing “3+1” DCI size alignment can be maintained.

On the other hand, the baseline approach is to support single-stage DCI as it is sufficient when only a few serving cells are co-scheduled, e.g., 2-cell joint scheduling. Moderator suggests focusing on single-stage DCI first then further study two-stage DCI format if time allows.

### 1st round of discussions

#### Proposal 2-9:

* At least single-stage DCI format is supported for multi-cell PDSCH or PUSCH scheduling.
* FFS two-stage DCI format

Companies are encouraged to provide comments in the table below.

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| **Company** | **Comment** |
| Qualcomm | P2-9: in general OK.  We do not think it is appropriate to consider two-stage DCI in this WI considering the necessary work load for that. It will require resolving a lot of open issues. Therefore, we are OK to delete the sub-bullet, so that we do not need to study two-stage DCI in the next meeting. |
| Nokia/NSB | Support, but don’t really see a need for the FFS.  Looking at how much time we have available, agreeing on the details of two-stage DCI format seems to be not possible – besides the negative effects of two-state DCI on decoding latency, increased PDCCH blocking probability (due to linked PDCCH candidates) as well as higher effective BLER (… as both DCIs need to be correctly decoded). |
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## Other related issues

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| * **Samsung** * *Proposal 5: The value in the search space equation for PDCCH monitoring for multi-cell scheduling corresponds to a set of co-scheduled cells. FFS on the method for associating a search space set and a set-level CIF.* * *Proposal 6: Define the counting of PDCCH candidates and non-overlapping CCEs for multi-cell scheduling.* * **LG Electronics** * *Proposal #7: Discuss how to determine the n\_CI value for the multi-cell scheduling, based on the following three alternatives.* * *Alt A: The n\_CI value is determined as the CIF value configured for each scheduled cell schedulable by the multi-cell DCI (this could be associated with the Alt 1 for PDCCH candidate configuration).* * *Alt B: The n\_CI value is determined as the CIF value configured for each combination of scheduled cells schedulable by the multi-cell DCI (this could be associated with the Alt 2 for PDCCH candidate configuration).* * *Alt C: The n\_CI value is determined/configured for the multi-cell DCI itself (this could be associated with the Alt 3 for PDCCH candidate configuration).* * **Qualcomm** * *Proposal 5: Re-use CIF/nCI framework* * *Multiple cells can be mapped to a CIF/nCI value of a DCI format monitored on a scheduling cell*   + - The DCI may schedule data on one, some, or all of the cells mapped to the CIF/nCI value     - A set of PDCCH candidates associated with the CIF/nCI value is for a DCI format that can schedule data on the cells – size determination and DCI parsing is based on this * *Different CIF/nCI values can be assigned to different sets of cells scheduled from the same scheduling cell* * *Legacy cross-carrier single-cell scheduling can be part of the same framework from the same scheduling cell* * *A DCI format for multi-cell scheduling is configured to be monitored on USS set(s) and the DCI format is a non-fallback DCI format* * *I.e., CSS set(s) and fallback DCI format(s) do not support multi-cell scheduling* * **FGI** * *Proposal 8: Reuse search space linking method for configuration of a search space for a DCI scheduling multiple cells.* |

# DCI field design

Based on contributions submitted by companies, below issues are prioritized for discussion in this meeting. Within each sub-section, the summary from moderator’s perspective is listed and followed by draft proposals for further discussion round by round.

## DCI field types

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| * **Huawei, HiSilicon** * *Proposal 1: For the single DCI scheduling multiple cells, some DCI fields can be predefined to be independent for separate PDSCHs, some fields can be predefined to be common for multiple PDSCHs, and the other fields can be configurable to be independent or common based on network decisions.* * **ZTE** * *Proposal 3: Discussing DCI fields one by one is preferred in case none of simple solution of avoiding discussing DCI fields one by one is adopted.* * *Proposal 4: Except the fields that must be separately indicated (e.g., NDI, RV), at most 4 elements can be designed for a configurable field, where each element corresponds to one separate indication of this field.* * **Spreadtrum Communications** * *Proposal 10: At least one stage DCI can be applied for multi-cell scheduling with a single DCI.* * *Proposal 11: For the multi-cell scheduling DCI, in order for payload reduction, all the fields of the DCI can be divided into three types:* * *First type field: common to the multi-cell PDSCHs/PUSCHs* * *Second type field: separate to the multi-cell PDSCHs/PUSCHs* * *Third type field: common or separate to the multi-cell PDSCHs/PUSCHs dependent on RRC configuration* * **CATT** * *Proposal 3: For supporting multi-cells PDSCHs/PUSCHs scheduled by a single DCI, the design of the DCI scheduling multiple PDSCHs/PUSCHs in Rel-17 can be reused as baseline, and RAN1 can discuss which bits field should be modified.* * **Vivo** * *Proposal 3. Regarding whether a DCI field should be shared among the scheduled cells or split into separate indications:* * *Some fields (e.g., CIF/BWP id/identifier DCI) can be shared by the scheduled cells.* * *Discussion for some of the fields (e.g., HARQ process/FDRA/TDRA/PUCCH related field) is needed* * *Other fields can be up to gNB configuration* * **China Telecom** * *Proposal 8: At least MCS, NDI, RV, HARQ process number, BWP can be separately indicated for the scheduled multiple cells in the multi-cell scheduling DCI* * **Lenovo** * *Proposal 6: The fields of multi-cell scheduling DCI are divided into three types:* * *Type-1: shared to all the scheduled carriers.* * *Type-2: separate to each of the scheduled carriers.* * *Type-3: shared to all the scheduled carriers or separate to each of the scheduled carriers dependent on RRC configuration.* * **Xiaomi** * *Proposal 5: It is up to the gNB’s configuration to determine whether the scheduling information can be shared or not for different scheduled cells.* * **Samsung** * *Proposal 3: For a DCI format used for multi-cell scheduling, RAN1 to conclude on:* * *which DCI fields are cell-common, by default or by configuration, and which DCI fields are cell-specific;* * *indication method for each cell-specific field:*   + - *explicit separate indication with restricted value set*     - *explicit differential indication*     - *single indication based on “multi-cell mapping”*     - *no indication* * *Tables 1 and 2 can be starting points for the RAN1 discussions.* * **OPPO** * *Proposal 7: The DCI fields in the new DCI format are discussed one by one regarding to shared indication vs. separated indication.* * **CAICT** * *Proposal 3: The bit fields for each cell scheduling in the DCI is preconfigured and indicated by one flag in the DCI.* * **Apple** * *Proposal 4: Further investigate whether to indicate the following fields separately for multiple PDSCHs/PUSCHs* * *FDRA* * *TDRA* * *MCS* * *NDI* * *RV* * *TCI* * *SRI* * **CMCC** * *Proposal 3. Two options can be considered as a new DCI format used for multi-cell PUSCH/PDSCH scheduling.* * *Option 1. Indicate shared fields and carrier specific fields by pre-defined rule or signalling.* * *Option 2. Same fields are used for all carriers and re-purpose the information fields for each carrier separately.* * **NTT DOCOMO** * *Proposal 1: Multi-carrier PDSCH/PUSCH scheduling with a single DCI is not supported by DCI format 0\_0/ and DCI format 1\_0.* * *Proposal 7: Discuss following alternatives for each field of the DCI scheduling multi-carrier PDSCH/PUSCH;* * *Alt.1: indicate single value (applicable to all scheduled cells or single cell).* * *Alt.2: indicate multiple values (each for each scheduled cell).* * *Alt.3: configurable between Alt.1 and Alt.2.* * *Alt.4: not support in the DCI scheduling multi-cell PDSCH/PUSCH.* * *Proposal 8: The following DCI fields of a multi-carrier scheduling DCI should indicate single value;* * *DCI format identifier* * *Carrier indicator* * *Proposal 9: The following DCI fields of a multi-carrier scheduling DCI should indicate multiple values for each scheduled cell separately;* * *New data indication* * *Redundancy version* * *HARQ process number* * **LG Electronics** * *Proposal #2: Discuss how to composite DCI fields in the multi-cell DCI, based on the following DCI composition types per DCI field.* * *[Categorization of DCI field types]* * *DCI field type 1: “Shared”*   + - *Alt 1: Shared-common* * *The value indicated via one DCI field is commonly applied for all the scheduled cells/TBs.*   + - *Alt 2: Shared-reference-cell* * *The value indicated via one DCI field is applied for only one of scheduled cells while a (pre-defined/configured) default value is applied for other scheduled cell.*   + - *Alt 3: Shared-single-cell* * *The DCI field is present only if a single cell is scheduled by multi-cell DCI while the field is not present if multiple cells are scheduled by the multi-cell DCI.*   + - *Alt 4: Shared-state-extension* * *Each DCI state (or code-point) to be indicated via one field corresponds to a combination of multiple values for multiple cells (unlike the legacy single-cell scheduling where each DCI state corresponds to only one value for single cell).* * *DCI field type 2: “Separate”*   + - *Alt A: Separate-reduced* * *A DCI has multiple separate fields corresponding to multiple scheduled cells/TBs, and the field size can be reduced compared to single-cell scheduling case considering DCI overhead.*   + - *Alt B: Separate-delta* * *Full DCI information is indicated for only one of scheduled cells, and only delta value (relative to the full information) is indicated for other scheduled cell.* * *DCI field type 3: “Omit”*   + - *The field is omitted in a multi-cell DCI.* * *[Composition of multi-cell DCI fields]* * *Resource allocation fields*   + - *FDRA field: Separate-reduced (or Shared-common in some cases)*     - *TDRA field: Separate-reduced (or Shared-state-extension)* * *HARQ related fields*   + - *MCS field: Separate-reduced (or Separate-delta in some cases)*     - *NDI/RV field: Separate-reduced (or Shared-common for RV field)*     - *HARQ ID field: Separate-reduced (or Shared-common)* * *MIMO related fields*   + - *Antenna port field: Separate-reduced*     - *TCI field: Separate-reduced (or Shared-state-extension)*     - *SRI field: Separate-reduced (or Shared-state-extension)*     - *Precoding info & number of layers: Separate-reduced*     - *PTRS-DMRS association: Separate-reduced (or Shared-reference/single-cell)*     - *DMRS sequence initialization: Shared-common or Shared-reference/single-cell (or Omit)* * *Other fields: Shared (or Omit)*   + - *BWP indicator, VRB-to-PRB mapping, PRB bundling size, Rate matching indicator, ZP CSI-RS trigger, Type-3 codebook request, SRS request, CBGTI, CBGFI, Priority indicator, Minimum scheduling offset, SCell dormancy indication, UL/SUL indicator, FH flag, DAI, TPC, CSI request, Beta\_offset indicator, UL-SCH indicator, LBT parameter field, OLPC parameter set indication, Invalid symbol pattern indicator* * **MediaTek** * *Proposal 3: For R18 multi-cell PUSCH/PDSCH scheduling with a single DCI, it is up to network RRC configuration to assign which DCI fields to be common bit fields and which DCI fields to be designated bit fields (which would be assigned independently for each scheduled cell)* * *For example, through a bitmap to determine each DCI bit field is a common bit field or a designated bit field with one bit* * **Ericsson** * *Proposal 9: For mc-DCI scheduling PDSCH on multiple cells, at least the following fields are common for the multiple scheduled PDSCHs* * *Downlink assignment index* * *TPC command for scheduled PUCCH* * *PUCCH resource indicator* * *PDSCH-to-HARQ-feedback timing indicator* * **Qualcomm** * *Proposal 4:* * *For each DCI field, select/conclude one of the following:*   + - *Opt.1: Unchanged* * *Fields that are irrelevant to multi-cell scheduling* * *E.g., DCI format identifier, SCell dormancy indication, PDCCH monitoring adaptation, CSI request, sidelink assignment index*   + - *Opt.2: Common indication* * *Single field indicates a common value for all the scheduled cells* * *E.g., HARQ process number, ChannelAccess-CPext, minimum scheduling offset*   + - *Opt.3: Joint indication* * *Single field indicates a set of configured values for a set of scheduled cells* * *E.g., BWP indicator, FDRA, TDRA, rate-matching indicator, ZP CSI-RS indicator*   + - *Opt.4: Per-cell indication* * *Per-cell field for each scheduled cells* * *E.g., NDI, RV* * **FGI** * *Proposal 1: To discuss the extension information of scheduling DCI for the multiple cell scheduling via single DCI.* * *Proposal 2: The extension information includes HARQ process number, NDI and TDRA/FDRA information.* |

### Moderator summary and proposals based on contributions

For multi-cell scheduling DCI, signaling overhead can be reduced when some fields can be applicable or common for all the co-scheduled carriers in case of same cell group, e.g., 24-bit CRC, 3-bit PDSCH-to-HARQ\_timing indicator, 3-bit PUCCH resource indicator, 2-bit TPC, 2-bit counter DAI, 2-bit total DAI, 1-bit identifier. These fields can be shared for all the co-scheduled carriers.

Regarding the carrier-specific fields, e.g., MCS, NDI and RV, these fields should be separately indicated in the multi-cell scheduling DCI for each of the co-scheduled carriers. Further overhead reduction, e.g., one-bit RV indication as Rel-16 NR-U or differentiated MCS indication, can be discussed in next step.

For some fields, a single frequency domain resource allocation can be shared for all the co-scheduled carriers in case of intra-band CA case or cell-specific frequency domain resource allocation indication should be included for each of the co-scheduled carriers in case of inter-band CA. In this way, the frequency domain resource allocation can be shared or specific dependent on network configuration, which is similar to time domain resource allocation. For MIMO related fields, those can be shared or separate dependent on network configuration.

13 companies [Huawei, Spreadtrum, vivo, China Telcom, Lenovo, OPPO, Samsung, CMCC, NTT DOCOMO, LG, MediaTek, Ericsson, Qualcomm] propose dividing the fields of the multi-cell scheduling DCI into 3 or 4 types: shared for all the co-scheduled cells, separate for each co-scheduled carrier, shared or separate dependent on network configuration, as well as omitted. Since we can list all the necessary fields for multi-cell scheduling DCI, the omitted field type may not be needed for time being.

Even for shared field, there are several options for detailed design, e.g., carrier indicator field; for separate field, e.g., MCS, some companies prefer independent MCS field for each co-scheduled carrier while others prefer differential MCS indication for co-scheduled carriers for overhead reduction. Moderator suggests no detailed discussion in this meeting. Same as BWP indicator, HARQ process number field, we can put those FFS.

For TDRA indication, several companies [vivo, Samsung, LG] propose/consider a common TDRA field is included in the multi-cell scheduling DCI pointing to one row of a TDRA table defined for the co-scheduled cells with each row indicating multiple SLIVs for the multiple scheduled cells. Moderator suggests the discussion is focused on whether TDRA field is common or separate to the co-scheduled cells with no detailed discussion in this meeting.

### 1st round of discussions

#### Proposal 3-1:

* For multi-cell scheduling DCI, all the fields of the DCI can be divided into three types:
* Type-1 field: A single field applicable/common to all the co-scheduled cells
* Type-2 field: Separate field for each of the co-scheduled cells
* Type-3 field: Common or separate to each of the co-scheduled cells dependent on configuration

Companies are encouraged to provide comments in the table below.

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| **Company** | **Comment** |
| Qualcomm | P3-1: suggest to discuss each field one by one.  We think there should be another type of field (can be called as joint indication field) where it is a single field, but a codepoint of the field indicates same or different values for different co-scheduled cells (the values are configured by RRC). This is similar to TDRA for multi-slot PDSCH/PUSCH scheduling in Rel-16/17. |
| Nokia/NSB | Support |
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#### Proposal 3-2:

* For the multi-cell scheduling DCI,
* Type-1 fields at least include below:
  + Identifier for DCI formats
  + Carrier indicator
  + Downlink assignment index
  + TPC
  + PUCCH resource indicator
  + PDSCH-to-HARQ timing indicator
* Type-2 fields at least include below:
  + Modulation and coding scheme
  + New data indicator
  + Redundancy version
* Type-3 fields at least include below:
  + PRB bundling size indicator
  + Rate matching indicator
  + ZP CSI-RS trigger
  + Antenna port(s)
  + TCI
  + SRS request
  + DMRS sequence initialization
* FFS
  + Bandwidth part indicator
  + Time domain resource assignment
  + Frequency domain resource assignment
  + VRB-to-PRB mapping
  + HARQ process number
  + One-shot HARQ-ACK request
  + ChannelAccess-CPext
  + Other fields

Companies are encouraged to provide comments in the table below.

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| **Company** | **Comment** |
| Qualcomm | P3-2:  List of Type-1 fields: OK  List of Type-2 fields: NDI and RV can be Type-2. However, MCS should be further discussed.  List of Type-3 fields: we think many of them should be joint indication field. |
| Nokia/NSB | On Type 1 fields:  The ‘carrier indication’ is not fully clear here – is this the indication of the scheduled cells? (maybe use a different wording as the current carrier indication refers to CIF & n\_CI).  On Type 2 fields: we think that e.g. MCS, RV or NDI could be potentially also actually of Type 3 (e.g. if using single cell DCI for re-tx, intra-band CA could lead to same MCS). |
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## Indication of scheduled cells

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| * **ZTE** * *Proposal 5: For designing the CIF filed in the multi-cell scheduling DCI, dynamic or semi-static combination of the multiple scheduled cells should be determined firstly.* * **Nokia, Nokia Shanghai Bell** * *Proposal 3.3.5: The scheduled cells are indicated in a DCI field pointing to a table of scheduled cell(s).* * *The table of scheduled cell(s) to be scheduled is RRC configured for the UE.* * *Support separate table configurations for the multi-cell scheduling DCI for PDSCH and PUSCH.* * **CATT** * *Proposal 2: There are two options on the actual number of scheduled cells by a DCI as follows.* * *Option-1: is fixed to N, the scheduled cells are configured by higher layer.* * *Option-2: can dynamically change from 1 to M, the combination of scheduled cells is indicated by DCI, e.g. carrier indicator field.* * **China Telecom** * *Proposal 2: The multiple cells that can be scheduled by the multi-cell scheduling DCI are configured by RRC signaling. Detailed configuration signaling are FFS.* * *Proposal 3: The actually scheduled cells among the cells being able to be scheduled by the multi-cell scheduling DCI are determined dynamically by the DCI indication.* * **NEC** * *Proposal 2: The set of cell combinations are configured for each CIF. To determine which cell combination is scheduled via the CIF, down-select the two options:* * *Option A: a new field in DCI to switch the cell combination used in the set for the CIF* * *Option B: a reserved/predefined value in existing field to indicate enabled and disabled of cells in the set for the CIF.* * **Samsung** * *Proposal 2: RRC configures ‘set-level’ CIF values that correspond to sub-sets of co-scheduled cells from a set of co-scheduled cells.* * **OPPO** * *Proposal 3: The indication scheme for scheduled cells needs to be defined, e.g. indicated cells in DCI directly, or indicated by pre-configured cell combination in DCI.* * **InterDigital** * *Proposal 1: Study indicating scheduling information for multiple cells using the same DCI bitfield.* * *Proposal 2: A bitfield in the DCI can indicate the scheduled cells.* * **CMCC** * *Proposal 2. The sets of scheduled cells can be pre-configured by RRC signaling, and the new multi-cell scheduling DCI is used to dynamically indicate which set to be scheduled.* * **LG Electronics** * *Proposal #1: Discuss how to indicate scheduled cell(s) via the multi-cell DCI, based on the following two options.* * *Option 1: Based on CIF field only*   + - *Different CIF values are configured between multi-cell scheduling case and single-cell scheduling case.* * *Option 2: Based on 1-bit flag and CIF field*   + - *The 1-bit flag indicates whether the DCI schedules multi-cell or single-cell, and the CIF field indicates multi-cell CIF value or single-cell CIF value according to the 1-bit flag.* * **Intel** * *Proposal 4* * *For multi-cell scheduling, a joint carrier and BWP indication field is included in the DCI to determine a set of carriers and BWPs from a configured table.* * *Dynamic switching between single-cell and multi-cell scheduling is supported.* |

### Moderator summary and proposals based on contributions

Regarding the indication of co-scheduled cells by a multi-cell scheduling DCI, 11 companies [ZTE, Nokia/NSB, CATT, China Telcom, NEC, Samsung, OPPO, Interdigital, CMCC, LGE, Intel] propose single carrier indicator field in the multi-cell scheduling DCI for indicating the co-scheduled cells. Majority companies prefer predefining a table with each row defining a combination of scheduled cells and using DCI to indicate one row of the table. So the DCI overhead can be reduced and the scheduling flexibility is guaranteed. Moderator suggests below proposal to capture a high-level design.

Considering different UE capabilities in UL CA and DL CA, it is reasonable to predefine two tables for DL and UL multi-cell scheduling, respectively.

### 1st round of discussions

#### Proposal 3-3:

* For multi-cell scheduling, the co-scheduled cells are indicated by carrier indicator pointing to one row of a table defining combinations of scheduled cells.
* The table is configured by RRC signaling.
* Separate tables can be configured for multi-cell PDSCH scheduling and multi-cell PUSCH scheduling.

Companies are encouraged to provide comments in the table below.

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| **Company** | **Comment** |
| Qualcomm | P3-3: generally OK.  On the 2nd sub-bullet, we are not sure if the separate tables here mean fully independent tables (we think not). We propose to put “FFS” on the 2nd sub-bullet for now. |
| Nokia/NSB | Support  On the comment by QC, the point being that PDSCH & PUSCH operation is independent (and there may be potentially less UL CA cells than DL CA cells). So having separate configuration for PUSCH & PDSCH scheduling seems to be needed. |
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## Other related issues

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| * **ZTE** * *Proposal 9: The fields for Rel-16/17 feature is supported and can be configurable in the multi-cell scheduling DCI.* * **Nokia, Nokia Shanghai Bell** * *Proposal 3.5.2: For mixed SCS multi-cell DCI scheduling operation, apply the Rel-16 processing timelines as if the multi-DCI represented individual single-cell DCI, each scheduling a different carrier.* * **Spreadtrum Communications** * *Proposal 12: The gap between PDCCH end symbol and the starting position of PDSCH defined in 38.214 should be applied for multi-cell scheduling with a single DCI when the SCS of scheduled cell is different from the scheduling cell.* * **Vivo** * *Proposal 4. For FDRA in mc-DCI, the FDRA granularity may be scaled or determined considering the BW of all the scheduled cells to reduce DCI size.* * **NEC** * *Proposal 3: RRC can configure additional scheduling cell group. Within scheduling cell groups, DCI bit field is shared by cells in scheduling cell groups. Among scheduling cell groups, DCI bit fields are specific for each scheduling cell groups.* * **Langbo** * *Proposal 1: Per scheduled cell configuration or per scheduling cell configuration can be considered for multi-cell PDSCH/PUSCH scheduling.* * *Proposal 2: Co-scheduled cells are considered jointly as a virtual cell for search space design when multi-cell PDSCH/PUSCH scheduling is configured.* * *Proposal 4: Both absolute indication and differential indication are supported by the DCI fields designated for multi-cell PUSCH/PDSCH scheduling.* * **Intel** * *Proposal 3* * *A number of cells can be grouped for multi-cell scheduling, where some DCI fields may not be shared between different groups.* * *Proposal 5* * *For multi-cell scheduling, a row of the TDRA table can configure separate resource allocation in time for all the configured cells.* * *Repetition is not supported if more than one PDSCHs or PUSCHs are scheduled for multi-cell scheduling.* * *Proposal 6* * *For multi-cell scheduling, a resource allocation type is configured or dynamically indicated in the DCI, which is commonly applied for the scheduled PDSCHs/PUSCHs.* * *A reference cell is defined to determine the FDRA size in the DCI.* * *Proposal 7* * *2 TBs are supported for multi-cell PDSCH scheduling.* * *For multi-cell PDSCH/PUSCH scheduling,*    + - *MCS is commonly applied for the scheduled PDSCHs (1st and 2nd TB), and PUSCHs, respectively.*     - *RV and NDI bitmap is defined, where each bit in the bitmap is used to indicate the RV and NDI for each scheduled PDSCH (1st and 2nd TB) and PUSCH, respectively.* * *Proposal 8* * *HARQ process number is commonly applied for the scheduled PDSCHs (1st and 2nd TB), and PUSCHs, respectively.* * *Proposal 10* * *Single PRI and K1 per DCI are included per DCI.* * *HARQ-ACK information corresponding to PDSCHs in one codebook scheduled by the DCI is multiplexed in a single PUCCH in a slot that is determined based on K1, where K1 is the slot offset between the last PDSCH (with the last ending symbol) and the PUCCH.* * *Proposal 13* * *Both Rel-15/16 TCI framework and Rel-17 unified TCI framework are supported for multi-cell scheduling.* * *With Rel-15/16 TCI framework, different PDSCHs scheduled by a DCI may use default TCI state or DCI-indicated TCI state depending on the delay between DCI and scheduled PDSCH.* * *With Rel-15/16 TCI framework, UE may also expect the activated TCI states are not changed in the span from first PDSCH to last PDSCH that are scheduled by the same DCI.* * **Charter Communications** * *Proposal 1: Consider enhanced multi-carrier operation where a single DCI can schedule PDSCH on three or more cells, including SCells with a dormant BWP, for energy-efficient and low-latency NR performance.* * **Qualcomm** * *Proposal 8:* * *Support SCell deactivation and SCell dormant BWP for a subset or all of cells configured with multi-cell scheduling with a single DCI* * *FFS spec impact e.g., application delay, DCI sizing/parsing, etc* * *Proposal 9:* * *Support power efficiency operation for CA with multi-cell scheduling with a single DCI, e.g.:*   + - *Opt.1: Minimum scheduling offset for power efficiency adaptation* * *So that the UE (and possibly NW) can adapt BB/RF bandwidth(s) dynamically* * *FFS: Necessary min scheduling offset for bandwidth(s) adaptation*   + - *Opt.2: Scheduling cell switch* * For example: * *State 1: DCI for scheduling FR2 cells is monitored/received on a FR1 cell* * *State 2: DCI for scheduling FR2 cells is monitored/received on FR2 cell(s)* * *The UE determines state 1 or state 2 depending on NW signalling or condition(s)* * *FFS: Necessary time gap for scheduling cell switch* |

# HARQ enhancements

Based on contributions submitted by companies, below issues are prioritized for discussion in this meeting. Within each sub-section, the summary from moderator’s perspective is listed and followed by draft proposals for further discussion round by round.

## Background and submitted proposals

Regarding this issue, companies’ views are summarized as below:

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| * **Huawei, HiSilicon** * *Proposal 9: Design of HARQ-ACK codebook needs be discussed in the case of multi-cell scheduling by a single DCI.* * **ZTE** * *Proposal 8: Shared or separate indication for the fields of HARQ-ACK feedback should be determined considering both overhead reduction and spec impact.* * **Vivo** * *Proposal 8. For type 1 HARQ-ACK codebook, an extension depending on the TDRA indication for multi-cell scheduling to the K1 set should be considered. Moreover, further enhancement on top of the legacy K1 set extension may be needed.* * *Proposal 9. For type 2 HARQ-ACK codebook, the multi-cell scheduling is not expected to be configured with CBG-based or multi-PDSCH scheduling simultaneously for any serving cell within a same PUCCH cell group.* * *Proposal 10. For the type 2 HARQ-ACK codebook, HARQ-ACK bits corresponding to mc-DCI should be contained in a separate sub-codebook apart from the sub-codebook for sc-DCI.* * *Proposal 11. For the type 2 HARQ-ACK sub-codebook, the C-DAI/T-DAI can be counted per mc-DCI.* * **Lenovo** * *Proposal 10: For Type-2 HARQ-ACK codebook determination, the number of HARQ-ACK information bits for each multi-cell PDSCH scheduling DCI is determined based on the maximum number of carriers scheduled by the multi-cell PDSCH scheduling DCI.* * *Proposal 11: The carriers scheduled by a single DCI are included in same cell group.* * **Samsung** * *Proposal 8: Define a reference PDSCH for determination of the PUCCH resource/slot with HARQ-ACK corresponding to multiple PDSCHs scheduled on multiple serving cells by a multi-cell scheduling DCI format.* * *Proposal 9: Consider requirements for supporting Type-1 HARQ-ACK codebook for co-scheduled PDSCHs on a set of co-scheduled cells with different SCS configurations and joint or separate TDRA tables.* * *Proposal 10: Determine counter DAI definition and ordering of HARQ-ACK information bits in a Type-2 HARQ-ACK codebook for multi-cell scheduling.* * *Proposal 11: Don’t support HARQ bundling corresponding to multiple scheduled PDSCHs on a set of co-scheduled cells.* * *Proposal 12: Support generation of a Type-3 HARQ-ACK codebook corresponding to both individual cells and sets of co-scheduled cells.* * *Proposal 13: Out-of-order (OoO) scheduling requirement for the case of multi-cell scheduling is applicable for each corresponding PDSCH/PUSCH.* * **Apple** * *Proposal 2: Multi-cell scheduling DCI shall not introduce out-of-order PDSCH/PUSCH scheduling or out-of-order HARQ-ACK for any scheduled cell at least for single-TRP operation.* * *Proposal 5: Use the Type-2 HARQ-ACK codebook construction mechanism for above 52.6GHz as the starting point for the Type-2 HARQ-ACK codebook construction with multi-cell scheduling DCI.* * **NTT DOCOMO** * *Proposal 11: RAN1 should discuss the following aspects related to HARQ feedback for multi-carrier PDSCH scheduling with a single DCI;* * *applicable HARQ-ACK codebook and required enhancements for each type of codebook if any* * *HARQ feedback timing determination* * *PUCCH cell group limitation* * **LG Electronics** * *Proposal #8: Discuss how to align HARQ-ACK slot timing corresponding to multiple PDSCH receptions on the cells scheduled by a same multi-cell DCI.* * *Proposal #9: Discuss how to construct Type-1 HARQ-ACK codebook in case with multi-cell PDSCH scheduling, in terms of following two aspects.* * *SLIV pruning procedure for the cell schedulable by the multi-cell DCI* * *Determination of K1 set for the cell schedulable by the multi-cell DCI* * *Proposal #10: Discuss how to construct Type-2 HARQ-ACK codebook in case with multi-cell PDSCH scheduling, in terms of the following aspects.* * *DAI counting (and corresponding sub-codebook construction) is performed separately between multi-cell scheduling case and single-cell scheduling case.* * *Determination on the number of HARQ-ACK bits per DAI (and the ordering of HARQ-ACK bits within a DAI) for the multi-cell scheduling case needs to be considered.* * *Proposal #11: Discuss some other aspects related to the multi-cell PDSCH/PUSCH scheduling, including the followings.* * *How to indicate TB disabling for PDSCH* * *How to handle scheduled but deactivated Scell* * *How to handle the out-of-order HARQ issue* * **Intel** * *Proposal 11* * *Type-1 HARQ-ACK codebook is generated according to extended K1 based on K1 for reference PDSCH and slot offset between reference PDSCH and PDSCH in different CCs.* * *Further study on how to derive slot offset between reference PDSCH and PDSCH in different CCs.* * *Proposal 12* * *Type-2 HARQ-ACK codebook considers at least two sub-codebooks for single PDSCH and multi-cell PDSCH scheduling.*   + - *Further study the case with CBG transmission*     - *Further study reference PDSCH for serving cell index to determine DAI order* * **Qualcomm** * *Proposal 7:* * *Support HARQ-ACK codebook that contains HARQ-ACK bits for PDSCH reception(s) scheduled by DCIs for single-cell scheduling and by DCIs for multi-cell scheduling* * *Support all HARQ-ACK codebook types* * *For Type-2, consider re-using HARQ-ACK codebook construction for multi-slot PDSCH scheduling*   + - *Concatenating two sub-codebooks:* * *1st sub-codebook is for PDSCH(s) scheduled by DCI(s) for single-cell scheduling* * *2nd sub-codebook is for PDSCH(s) scheduled by DCI(s) for multi-cell scheduling* * *DAI counting is independent for the sets of DCI(s) for single-cell scheduling and multi-cell scheduling*   + - *CBG based re-transmission is not supported* |

## Moderator summary and proposals based on contributions

Regarding HARQ-ACK feedback timing determination, if a single field of PDSCH-to-HARQ\_ACK feedback timing indicator is included in the multi-cell scheduling DCI, it is not clear which one of the co-scheduled PDSCHs is regarded as the reference PDSCH so as to determine the PUCCH slot based on the reference PDSCH and the indicated K1 value. This issue is mentioned by 5 companies [vivo, Samsung, NTT DOCOMO, LGE, Intel] and moderator thinks it is necessary to have one agreement to make it clear. How to define the reference PDSCH can be FFS since some companies prefer the last PDSCH while other companies prefer the PDSCH on one scheduled cell with highest or lowest serving cell index.

For Type-1 HARQ-ACK codebook, as mentioned by 3 companies [vivo, LG, Samsung], the determination of the Type-1 codebook is related to the design of TDRA indication in the multi-cell PDSCH scheduling DCI. If common TDRA field is included in the multi-cell scheduling PDSCH where a TDRA table is defined for the co-scheduled cells with each row indicating multiple SLIVs for the multiple scheduled cells, then SLIV pruning and K1 set extension need to be considered. For time being, moderator propose suspending this issue until the common TDRA indication with a TDRA table defined with each row indicating multiple SLIVs for the multiple scheduled cells is agreed.

For Type 2 HARQ-ACK codebook, as mentioned by 7 companies [Huawei, vivo, Lenovo, Samsung, LG, Intel, Qualcomm], there are several issues need to be resolved: a first issue is the DAI counting whether it is updated per DCI or per PDSCH or per multi-cell scheduling DCI; a second issue is whether CBG-based transmission can be configured with multi-cell scheduling in same cell group; a third issue is how to generate 2 sub-codebooks as Rel-17 multi-slot PDSCH scheduling, where a first sub-codebook comprises HARQ-ACK information bits for PDSCHs scheduled by single-cell scheduling DCIs and a second sub-codebook comprise HARQ-ACK information bits for PDSCHs scheduled by multi-cell scheduling DCIs; a fourth issue is how to generate HARQ-ACK information bits for a multi-cell scheduling DCI considering the DCI may be missed by UE; a fifth issue is how to order the HARQ-ACK information bits for PDSCHs scheduled by a same DCI in case a single DAI included in the DCI. Moderator thinks such issues are not controversial and can be discussed in the first meeting.

For Rel-15/16/17 Type-2 HARQ-ACK codebook, there are at most two sub-codebooks. The first sub-codebook comprises TB-based HARQ-ACK information bits for PDSCHs scheduled by single slot scheduling DCI. The second sub-codebook comprises CBG-based HARQ-ACK information bits for single-slot PDSCH scheduling or TB-based HARQ-ACK information bits for multi-slot PDSCH scheduling in a same serving cell. This is because CBG-based transmission and multi-slot PDSCH scheduling cannot be configured simultaneously in a same PUCCH cell group. Considering limited TU for Rel-18 multi-carrier enhancements, for simplicity, we need restriction of simultaneous configuration of the multi-cell scheduling, CBG-based transmission and single-cell multi-slot PDSCH scheduling within a same cell group. As a result, there are at most two sub-codebooks for the Type-2 HARQ-ACK codebook, one for single-cell scheduling and another for multi-cell scheduling.

## 1st round of discussions

#### Proposal 4-1:

* PDSCH-to-HARQ\_timing indicator in the multi-cell PDSCH scheduling DCI indicates a slot level offset between a reference PDSCH of the co-scheduled PDSCHs and the PUCCH slot.
* FFS: the reference PDSCH
* FFS: different SCS between reference PDSCH and other co-scheduled PDSCHs

Companies are encouraged to provide comments in the table below.

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| **Company** | **Comment** |
| Qualcomm | P4-1: OK |
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#### Proposal 4-2:

* All HARQ-ACK codebook types (Type-1/2/3) are applicable when multi-carrier PDSCH scheduling is configured.

Companies are encouraged to provide comments in the table below.

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| **Company** | **Comment** |
| Qualcomm | P4-2: OK but if there is a concern, we can make this as a working assumption. |
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#### Proposal 4-3:

* For Type-2 HARQ-ACK codebook, UE does not expect the multi-cell scheduling is configured with CBG-based transmission or multi-slot scheduling simultaneously within a same PUCCH cell group.

Companies are encouraged to provide comments in the table below.

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| **Company** | **Comment** |
| Qualcomm | P4-3: OK |
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#### Proposal 4-4:

* For Type-2 HARQ-ACK codebook, two sub-codebooks are generated with a first sub-codebook comprising HARQ-ACK information bits for PDSCH(s) scheduled by single-cell scheduling DCI(s) and a second sub-codebook comprising HARQ-ACK information bits for PDSCH(s) scheduled by multi-cell scheduling DCI(s).
  + Separate DAI counting for single cell scheduling DCI(s) and multi-cell scheduling DCI(s)
  + Type-2 HARQ-ACK codebook is generated by concatenating the first sub-codebook and the second sub-codebook.
  + FFS: Number of HARQ-ACK information bits for each multi-cell scheduling DCI
  + FFS: HARQ-ACK information bits ordering for co-scheduled PDSCHs

Companies are encouraged to provide comments in the table below.

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| **Company** | **Comment** |
| Qualcomm | 4-4: OK |
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# Proposals for GTW session:

## Proposals for 1st GTW session:

Based on the feedback from companies on the possible way forward, below proposals are prepared for online discussion:

## Proposals for 2nd GTW session:

# References

1. [R1-2203135](file:///D:\RAN1\RAN1%23109-e\tdocs\R1-2203135.zip) Discussion on multi-cell PUSCH/PDSCH scheduling with a single scheduling DCI Huawei, HiSilicon
2. [R1-2203207](file:///D:\RAN1\RAN1%23109-e\tdocs\R1-2203207.zip) Discussion on Multi-cell PUSCH/PDSCH scheduling with a single DCI ZTE
3. [R1-2203276](file:///D:\RAN1\RAN1%23109-e\tdocs\R1-2203276.zip) On multi-cell PUSCH/PDSCH scheduling with a single DCI Nokia, Nokia Shanghai Bell
4. [R1-2203346](file:///D:\RAN1\RAN1%23109-e\tdocs\R1-2203346.zip) Discussion on multi-cell PUSCH/PDSCH scheduling with a single DCI Spreadtrum Communications
5. [R1-2203448](file:///D:\RAN1\RAN1%23109-e\tdocs\R1-2203448.zip) Discussion on multi-cell PUSCH/PDSCH scheduling with a single DCI CATT
6. [R1-2203583](file:///D:\RAN1\RAN1%23109-e\tdocs\R1-2203583.zip) Discussion on multi-cell scheduling vivo
7. [R1-2203664](file:///D:\RAN1\RAN1%23109-e\tdocs\R1-2203664.zip) Discussion on multi-cell scheduling with a single DCI China Telecom
8. [R1-2203688](file:///D:\RAN1\RAN1%23109-e\tdocs\R1-2203688.zip) Discussion on Multi-cell PXSCH scheduling with a single DCI NEC
9. [R1-2203706](file:///D:\RAN1\RAN1%23109-e\tdocs\R1-2203706.zip) Discussion on multi-cell scheduling via a single DCI Lenovo
10. [R1-2203800](file:///D:\RAN1\RAN1%23109-e\tdocs\R1-2203800.zip) Discussion on the design of multi-cell scheduling with a single DCI xiaomi
11. [R1-2203842](file:///D:\RAN1\RAN1%23109-e\tdocs\R1-2203842.zip) Discussions on multi-cell PUSCH/PDSCH scheduling with a single DCI Langbo
12. [R1-2203925](file:///D:\RAN1\RAN1%23109-e\tdocs\R1-2203925.zip) Multi-cell PUSCH/PDSCH scheduling with a single DCI Samsung
13. [R1-2204026](file:///D:\RAN1\RAN1%23109-e\tdocs\R1-2204026.zip) Discussion on multi-cell PUSCH/PDSCH scheduling with a single DCI OPPO
14. [R1-2204087](file:///D:\RAN1\RAN1%23109-e\tdocs\R1-2204087.zip) Multi-cell scheduling with a single DCI InterDigital, Inc.
15. [R1-2204186](file:///D:\RAN1\RAN1%23109-e\tdocs\R1-2204186.zip) Discussion on multi-cell PUSCH/PDSCH scheduling with a single DCI CAICT
16. [R1-2204262](file:///D:\RAN1\RAN1%23109-e\tdocs\R1-2204262.zip) On multi-cell PUSCH/PDSCH scheduling with a single DCI Apple
17. [R1-2204324](file:///D:\RAN1\RAN1%23109-e\tdocs\R1-2204324.zip) Discussion on multi-cell PUSCH/PDSCH scheduling with a single DCI CMCC
18. [R1-2204398](file:///D:\RAN1\RAN1%23109-e\tdocs\R1-2204398.zip) Discussion on multi-cell PUSCH/PDSCH scheduling with a single DCI NTT DOCOMO, INC.
19. [R1-2204631](file:///D:\RAN1\RAN1%23109-e\tdocs\R1-2204631.zip) Discussion on Multi-cell PUSCH/PDSCH scheduling with a single DCI LG Electronics
20. [R1-2204697](file:///D:\RAN1\RAN1%23109-e\tdocs\R1-2204697.zip) On multi-cell PUSCH/PDSCH scheduling with a single DCI MediaTek Inc.
21. [R1-2204816](file:///D:\RAN1\RAN1%23109-e\tdocs\R1-2204816.zip) Discussions on multi-cell scheduling with a single DCI Intel Corporation
22. [R1-2204865](file:///D:\RAN1\RAN1%23109-e\tdocs\R1-2204865.zip) Multi-cell PUSCH/PDSCH scheduling with a single DCI Charter Communications
23. [R1-2204888](file:///D:\RAN1\RAN1%23109-e\tdocs\R1-2204888.zip) Multi-cell PUSCH/PDSCH scheduling with a single DCI Ericsson
24. [R1-2205051](file:///D:\RAN1\RAN1%23109-e\tdocs\R1-2205051.zip) Multi-cell PUSCH and PDSCH scheduling with a single DCI Qualcomm Incorporated
25. [R1-2205073](file:///D:\RAN1\RAN1%23109-e\tdocs\R1-2205073.zip) Discussion on Multicarrier scheduling with a single DCI FGI

# List of agreements:

## Agreements made in RAN1#109-e