**3GPP TSG RAN WG1 Meeting #105-e R1-210XXXX**

**e-Meeting, May 10th – 27th, 2021**

**Source: Moderator (Lenovo)**

**Title: Feature lead summary #1 on multi-cell scheduling via a single DCI**

**Agenda item:** **8.13.2**

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

# Introduction

This document summarizes the contributions submitted under the “**Multi-cell PDSCH scheduling via a single DCI**” agenda item of the Rel-17 work item on “Dynamic spectrum sharing (DSS)”.

The revised DSS WID [1] contains the following objective related to this agenda item:

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| This work item is limited to FR1, and includes the following objectives for NR Dynamic Spectrum Sharing (DSS):   * PDCCH enhancements for cross-carrier scheduling including [RAN1, RAN2]   + PDCCH of SCell scheduling PDSCH or PUSCH on P(S)Cell   + Study, and if agreed specify PDCCH of P(S)Cell/SCell scheduling PDSCH on multiple cells using a single DCI     - The number of cells can be scheduled at once is limited to 2     - The increase in DCI size should be minimized * Note: The total PDCCH blind decoding budget should not be changed as a result of this work * Note: These enhancements are not specific to DSS and are generally applicable to cross-carrier scheduling in carrier aggregation |

In Section 2, for multi-cell PDSCH scheduling via a single DCI, companies’ views on whether and how to support this feature are summarized at the end of Section 2. Based on majority companies’ views, some proposals and open questions are listed for discussion purpose.

In Section 3, the standard impacts on DCI format design and HARQ-ACK codebook determination are summarized. Since the main task at this stage is to determine whether to support the feature of using a single DCI scheduling two PDSCHs on two carriers, the standard impact issues can be discussed as soon as RAN1 agrees to support this feature.

In Section 4, miscellaneous issues are listed which can be treated in low priority.

In Section 6, the agreements made in previous RAN1 meetings are listed for reference.

# Summary of contributions

The section summarises key proposals and observations from submitted contributions.

## Summary of companies’ views

Regarding whether to support multi-cell PDSCH scheduling by a single DCI, companies’ views are summarized in below table.

**Company views:**

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| --- | --- |
| **Company** | **Key Proposals/Observations** |
| Nokia, Nokia Shanghai Bell | Proposal: Check if there is consensus to proceed to the specification phase, and if   * yes: discuss the next step of design details * no: do not continue the thread in RAN1#105, but escalate the issue to RAN#92 |
| Huawei, HiSilicon | *Observation 1: Using joint DCI scheduling 2 DL CCs is beneficial for reducing the PDCCH blocking rate under the assumptions captured in R1-2102138.*  *Observation 2: Using joint DCI scheduling can be beneficial for improving the PDSCH throughput for two carriers with the same SCS, depending on the number of DL CA users and PDCCH payload.*  *Observation 3: The benefits observed in R1-2102138 are applicable to CA of two carriers at least with the same SCS, including DSS carrier(s).*  *Observation 4: It is feasible to use joint DCI for scheduling more than 2 carriers including UL carriers. More benefits may be expected, which can be further discussed/studied.*  *Proposal:*   * *RAN1 agrees on the above observations for Objective 2 of Rel-17 DSS enh. WID* * *RAN1 sends LS to RAN to conclude that the specification work of Objective 2 is deferred*   + *Additional applicable scenarios can be further discussed in e.g. Rel-18.* |
| ZTE | *Observation 12: For one-to-two downlink scheduling in both inter-band CA and intra-band CA scenario,*   * *If most of the fields are separately indicated for one-to-two scheduling DCI, the gain of PDCCH blocking rate is marginal.* * *If most of the fields are shared for one-to-two scheduling DCI, throughput performance loss is observed.*   *Proposal 1: If RAN1 is to specify multi-cell scheduling, RAN1 specifies a generic mechanism for both uplink and downlink scheduling for 2 or more cells.* |
| vivo | *Proposal 1. Consider adopting one of the following alternatives for the way forward on joint scheduling:  Alt1. Support multi-cell scheduling PDSCH with single DCI in Rel-17 DSS WID for simplified scenarios, e.g., scheduled cells with same SCS in intra-band CA*  * Alt2. To stop working on this feature in Rel-17 DSS, while concluding that the multi-cell scheduling PDSCH with a single DCI will be addressed in Rel-18.*  *Proposal 2. Field type (i.e., shared or cell-specific) of each information field in joint-DCI needs to be investigated.* |
| Spreadtrum Communications | 1. *Support multi-cell PDSCH scheduling by single DCI.* 2. *The DCI fields should be discussed and study whether or not the scheduling information should be same or different for the multiple PDSCHs.* 3. *Support same DCI size for one-PDSCH scheduling and multi-PDSCH scheduling.* |
| CATT | Observation 1: The size of the bit field used for separate indication can be further discussed to achieve trade-off between overhead and flexibility.  Proposal 1: Multi-cell PDSCH scheduling via a single DCI should be supported considering it can bring significant benefits in terms of PDCCH capacity, PDSCH throughput and UE power saving. |
| OPPO | *Observation 1: CCE saving ratio is more than 10% for any DCI size even CA ratio is not large, e.g. CA ratio=30%. And for different combination scenarios, there is no significant difference in CCE saving ratio.*  *Observation 2: One-to-two scheduling can reduce PDCCH blockage significantly.*  *Observation 3: If single DCI scheduling PDSCH on two cells is supported, the following issues need to be considered*   1. *New DCI format design and DCI size alignment* 2. *Scheduling mode switch* 3. *PDCCH candidate determination* |
| Lenovo, Motorola Mobility | *Proposal 1: Support using a single DCI to schedule two PDSCHs on two cells.* |
| Intel | Proposal: RAN1 to specify multi-cell scheduling by a single DCI with reduced scope,   * It is limited to 2-cell scheduling * Same SCS is assumed for the two cells in 2-cell scheduling. |
| Apple | *Proposal 1: We do not observe enough justification and motivation to allow single DCI to schedule PDSCH on multiple cells.* |
| Samsung | *Proposal 1: If there is further study on a single DCI format scheduling on multiple cells, focus should be on scenarios and mechanisms that may offer throughput gains under realistic/typical operating conditions.* |
| InterDigital | *Proposal 1: Support a new DCI format to schedule two PDSCH in different cells.*  *Proposal 2: The size of the new DCI format is configurable.* |
| NEC | Proposal 1: CIF field for two-cell scheduling DCI can match the original size of CIF field for one-cell DCI (3-bit).  Proposal 2: Introduce one bit in scheduling DCI to support dynamic switching between scheduling a single cell and scheduling two cells.  Proposal 3: C-DAI counter is incremented by the number of scheduling DCI, while T-DAI counter is incremented by the total number of scheduled PDSCHs.  Proposal 4: K1 value is chosen with relative to the end of the first PDSCH in two-cell scheduling DCI.  Proposal 5: HARQ-ACK codebook is the multiplexing of ACK/NACKs of the two cells in order of carrier ID. |
| LG | Proposal #1: It is necessary to clarify/justify first on the technical motivation and benefits by introducing the single DCI based multi-cell PDSCH scheduling, on top of specifying the cross-CC PDSCH/PUSCH scheduling from Scell to Pcell.  Proposal #2: With the conclusion in RAN#91-e and according to the WID stating “Study, and if agreed specify …” and considering standard workload to specify this feature during the remaining Rel-17 time, it is reasonable for RAN1 (workload) to conclude that the multi-cell PDSCH scheduling by single DCI is not supported/specified in Rel-17. |
| NTT DOCOMO | Proposal 1:   * It may be better to postpone the discussion on PDCCH of P(S)Cell/SCell scheduling PDSCH on multiple cells using a single DCI in future release with considering non-DSS scenarios |
| Ericsson | * Evaluations under the agreed simulation framework indicate that single DCI scheduling PDSCH on two cells (mc-DCI) provides marginal or no performance gains. * Select one of below two alternatives for concluding the study related to the objective on “*PDCCH of P(S)Cell/SCell scheduling PDSCH on multiple cells using a single DCI*”   + Alt1 - Conclude that there is no consensus on performance gains for “PDCCH of P(S)Cell/SCell scheduling PDSCH on multiple cells using a single DCI” under the agreed simulation framework and stop further work on this Objective for Rel17.   + Alt2 – Conclude to stop further Rel17 work for this objective with the understanding that     - “PDCCH of P(S)Cell/SCell scheduling PDSCH on multiple cells using a single DCI” can be further studied for Rel18 targeting other scenarios e.g. intra-band CA with 4/8 CCs with same SCS, including FR2, and     - other PDCCH load reduction features such as multi-PDSCH scheduling (being specified in NR\_ext\_to\_71GHz WI) are also considered when evaluating the benefits of this feature |

## Initial proposals based on companies’ contributions

In this agenda, the performance evaluations in terms of reduced PDCCH blocking rate and PDSCH throughput were extensively discussed in RAN1#104 meeting and the detailed observations were captured in R1-2102138. Since RAN1#104 didn’t agree any new simulation assumptions for continuing the further evaluation it seems not necessary to discuss the more detailed simulation assumptions and methodologies. However, the concluded observations in R1-2102138 only captured the performance evaluation results from each company and didn’t reach consensus on whether the feature of using a single DCI to schedule two PDSCHs on two carriers is beneficial or not for reducing the PDCCH blocking rate and improving the PDSCH throughput compared to using two separate DCIs with each having 60 bits payload. Based on companies’ results, majority companies observed the reduced PDCCH blocking rate and PDSCH throughput improvement in some cases, e.g., same SCS, high CA UE percentage (100%) and large DCI payload sizes (96/108).

In order to fully conclude the evaluation on the two-cell joint scheduling from RAN1’s perspective, below proposals are proposed:

FL Proposal#1:

* Take below observations as conclusions:

On PDCCH blocking probability,

* Using a single DCI to schedule two PDSCHs on two carriers is beneficial for reducing the PDCCH blocking rate according to simulation assumptions in R1-2102138, compared to using two separate DCIs with each having 60 bits payload.

On PDSCH throughput,

* Using a single DCI to schedule two PDSCHs on two carriers can be beneficial for improving the PDSCH throughput for two carriers with same SCS, high CA UE percentage and large DCI payload according to simulation assumptions in R1-2102138, compared to using two separate DCIs with each having 60 bits payload.

Regarding above proposal, companies are encouraged to provide comments in the table below.

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| **Company** | **View** |
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## Way forward on whether/how to proceed this feature

To further check companies’ views on whether/how to proceed this work in Rel-17, below open questions on the possible way forward are prepared.

Open questions:

Q1: Do you support the normative work on scheduling two PDSCHs on two carriers via a single DCI in Rel-17 as existing WID?

Note: Existing WID is listed below for reference.

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| --- |
| * Study, and if agreed specify PDCCH of P(S)Cell/SCell scheduling PDSCH on multiple cells using a single DCI   + The number of cells can be scheduled at once is limited to 2   + The increase in DCI size should be minimized |

Companies are encouraged to provide comments in the table below.

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| **Company** | **View** |
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Q2: Do you support the normative work on scheduling two PDSCHs on two carriers via a single DCI in Rel-17 with limitation of same SCS for the two scheduled carriers?

Companies are encouraged to provide comments in the table below.

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| **Company** | **View** |
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Q3: Any other suggestions on possible way forward?

Companies are encouraged to provide comments in the table below.

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| **Company** | **View** |
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# Standard impact

## DCI format design

If scheduling multiple PDSCHs on multiple carriers via a single DCI is supported, one important thing is to design the DCI format. Based on the simulation results, for reducing PDCCH blocking probability, the DCI payload should be further compressed. So many fields in the DCI need to be shared for the PDSCHs scheduled on two carriers. However, this scheduling inflexibility may lead to throughput loss for inter-band CA case. Due to the large frequency separation between the scheduled carriers in inter-band CA, the channel conditions are less correlated. It is difficult to assume same link adaptation property on the scheduled carriers and use single fields for indicating same MCS, frequency domain resource allocation as well as time domain resource allocation. For full flexibility scheduling two PDSCHs on two carriers by a single DCI, almost all the related fields in the scheduling DCI need to be doubled except DAI, HARQ timing, PRI, TPC and 24-bit CRC. However, the larger the DCI payload size, the lower the transmission reliability and less coverage. As a result, further overhead reduction is required for the two-carrier scheduling DCI at the cost of potential reduction in scheduling flexibility.

In addition, in order not to increase UE’s PDCCH blind decoding budget as one target of Rel-17 DSS, another open issues is whether the multi-carrier scheduling DCI needs to schedule not only a single PDSCH but also two PDSCHs on two carriers when the UE is configured with such feature.

Regarding DCI format design, companies’ views are summarized as below:

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| --- | --- |
| Company | Key Proposals/Observations |
| ZTE | ***Observation 6****: If single DCI scheduling two PDSCHs on two carriers is supported, RAN1 needs to discuss whether to adopt shared indication or separate indication for each DCI field.*  ***Observation 7****: If single DCI scheduling two PDSCHs on two carriers is supported, RAN1 needs to further study how to handle the Rel-16 newly introduced DCI fields in DCI format 1\_1.*  ***Observation 8:*** *If single DCI scheduling two PDSCHs on two carriers is supported, RAN1 needs to further study whether to reuse DCI format 1\_1/1\_2 or introduce a new DCI format for one-to-two scheduling.*  ***Observation 9****: If single DCI scheduling two PDSCHs on two carriers is supported, RAN1 needs to further study how to indicate the two scheduled carriers.*  ***Observation 10****: If single DCI scheduling two PDSCHs on two carriers is supported, RAN1 needs to further study how to guarantee the current BD/CCE budget.*  ***Observation 12****: For one-to-two downlink scheduling in both inter-band CA and intra-band CA scenario,*   * *If most of the fields are separately indicated for one-to-two scheduling DCI, the gain of PDCCH blocking rate is marginal.* * *If most of the fields are shared for one-to-two scheduling DCI, throughput performance loss is observed.* |
| vivo | *Proposal 2. Field type (i.e., shared or cell-specific) of each information field in joint-DCI needs to be investigated.*  ***Observation 6. To support multi-cell scheduling, the following issues need to be resolved - DCI field design - Any restrictions on the scheduled cells to be paired for multi-cell scheduling - Framework of multi-cell scheduling - Whether to introduce a new DCI format  - PDCCH BD budget maintenance if multi-cell scheduling is enabled - HARQ-ACK codebook determination if multi-cell scheduling is enabled*** |
| Spreadtrum Communications | 1. ***The DCI fields should be discussed and study whether or not the scheduling information should be same or different for the multiple PDSCHs.*** 2. ***Support same DCI size for one-PDSCH scheduling and multi-PDSCH scheduling.*** |
| CATT | **Proposal 2: Two TBs should be scheduled separately on different serving cells for multi-cell PDSCH scheduling via a single DCI.**  **Proposal 3:** **The design of the compact DSS-DCI should be further studied.**  **Proposal 4: How to maintain the DCI budget due to the introduction of DSS-DCI needs further discussion.**  **Proposal 5: It can be supported that all of the target cells scheduled by a DSS DCI are different from the scheduling cell.** |
| OPPO | ***Observation 3: If single DCI scheduling PDSCH on two cells is supported, the following issues need to be considered***   1. ***New DCI format design and DCI size alignment*** 2. ***Scheduling mode switch*** 3. ***PDCCH candidate determination*** |
| Lenovo, Motorola Mobility | ***Observation 8: Two-cell scheduling DCI design requires less standardization effort if Rel-16 NR-U multi-PUSCH framework is reused.*** |
| InterDigital, Inc. | ***Proposal 2:*** *The size of the new DCI format is configurable.* |
| NEC | **Proposal 1: CIF field for two-cell scheduling DCI can match the original size of CIF field for one-cell DCI (3-bit).**  **Proposal 2: Introduce one bit in scheduling DCI to support dynamic switching between scheduling a single cell and scheduling two cells.** |
| NTT DOCOMO | **Observation 1:**   * **PDCCH of P(S)Cell/SCell scheduling PDSCH on multiple cells using a single DCI can improve PDCCH resource efficiency**   **Observation 2:**   * **How to indicate the scheduled cells by using a single DCI to the UE can be considered** * **Whether/how to support dynamic switching between scheduling a single cell and scheduling multiple cells can be considered**   **Observation 3:**   * **Whether the same TB and/or different TBs is/are scheduled on multiple cells can be considered** |

FL suggestions:

The issues about DCI format design can be discussed after RAN1 agree to support the multi-cell scheduling DCI.

## HARQ-ACK codebook design

Regarding HARQ-ACK codebook design, there is no issue for Type 1 HARQ-ACK codebook due to the semi-static codebook size. However, for Type 2 HARQ-ACK codebook, since each non-fallback DCI can schedule one or two PDSCHs, when the DCI is missed by UE, there may be misunderstanding between gNB and UE on the number of scheduled PDSCHs. In that sense, HARQ-ACK codebook ambiguity may happen. As a result, how to construct the Type 2 HARQ-ACK codebook needs to be considered in order to synchronize the same understanding between gNB and UE.

**Company views:**

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| --- | --- |
| **Company** | **Key Proposals/Observations** |
| ZTE | ***Observation 11****: If single DCI scheduling two PDSCHs on two carriers is supported, RAN1 needs to further study how to perform the corresponding HARQ-ACK feedback.* |
| CATT | ***Proposal 6: The HARQ feedback procedure need to be further studied.*** |
| NEC | ***Proposal 3: C-DAI counter is incremented by the number of scheduling DCI, while T-DAI counter is incremented by the total number of scheduled PDSCHs.***  ***Proposal 4: K1 value is chosen with relative to the end of the first PDSCH in two-cell scheduling DCI.***  ***Proposal 5: HARQ-ACK codebook is the multiplexing of ACK/NACKs of the two cells in order of carrier ID.*** |

FL suggestions:

The below issues can be discussed after RAN1 agree to support the multi-cell scheduling DCI.

* HARQ-ACK codebook determination
* DAI design

# Other issues

Regarding other issues not mentioned above, companies are encouraged to provide comments in the table below.

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| --- | --- |
| **Company** | **View** |
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|  |  |

# References

1. [R1-2104186](file:///D:\RAN1\RAN1%23105-e\tdocs\R1-2104186.zip) Way Forward On single DCI scheduling two cells Nokia, Nokia Shanghai Bell
2. [R1-2104233](file:///D:\RAN1\RAN1%23105-e\tdocs\R1-2104233.zip) Discussion on multi-carrier scheduling using single PDCCH Huawei, HiSilicon
3. [R1-2104341](file:///D:\RAN1\RAN1%23105-e\tdocs\R1-2104341.zip) Discussion on Multi-cell PDSCH Scheduling via a Single DCI ZTE
4. [R1-2104392](file:///D:\RAN1\RAN1%23105-e\tdocs\R1-2104392.zip) Discussion on joint scheduling vivo
5. [R1-2104446](file:///D:\RAN1\RAN1%23105-e\tdocs\R1-2104446.zip) Discussion on multi-cell PDSCH scheduling via a single DCI Spreadtrum Communications
6. [R1-2104496](file:///D:\RAN1\RAN1%23105-e\tdocs\R1-2104496.zip) Discussion on multi-cell PDSCH scheduling via a single DCI CATT
7. [R1-2104807](file:///D:\RAN1\RAN1%23105-e\tdocs\R1-2104807.zip) Discussion on multi-cell PDSCH scheduling via a single DCI OPPO
8. [R1-2104868](file:///D:\RAN1\RAN1%23105-e\tdocs\R1-2104868.zip) On multi-cell PDSCH scheduling via a single DCI Lenovo, Motorola Mobility
9. [R1-2104932](file:///D:\RAN1\RAN1%23105-e\tdocs\R1-2104932.zip) On 2-cell scheduling via single DCI Intel Corporation
10. [R1-2105132](file:///D:\RAN1\RAN1%23105-e\tdocs\R1-2105132.zip) Views on Rel-17 DSS Multi-cell PDSCH scheduling via a single DCI Apple
11. [R1-2105340](file:///D:\RAN1\RAN1%23105-e\tdocs\R1-2105340.zip) On a single DCI format scheduling on multiple cells Samsung
12. [R1-2105402](file:///D:\RAN1\RAN1%23105-e\tdocs\R1-2105402.zip) On the support of single DCI scheduling two cells InterDigital, Inc.
13. [R1-2105412](file:///D:\RAN1\RAN1%23105-e\tdocs\R1-2105412.zip) Multi-cell PDSCH scheduling via a single DCI NEC
14. [R1-2105442](file:///D:\RAN1\RAN1%23105-e\tdocs\R1-2105442.zip) Discussion on multi-cell PDSCH scheduling via a single DCI LG Electronics
15. [R1-2105724](file:///D:\RAN1\RAN1%23105-e\tdocs\R1-2105724.zip) Discussion on multi-cell PDSCH scheduling via a single DCI for NR DSS NTT DOCOMO, INC.
16. [R1-2105797](file:///D:\RAN1\RAN1%23105-e\tdocs\R1-2105797.zip) Study on single DCI scheduling PDSCH on multiple cells Ericsson

# List of agreements:

## Agreements made in RAN1#104-e

**Agreement**

* The proposal in section 2.6 of [R1-2102138](file:///D:\Doc\Contribution%20preparation\RAN1%23105\DSS\R1-2102138.zip) for PDCCH blocking probability is taken as RAN1 observation
* The proposal in section 2.6 of [R1-2102138](file:///D:\Doc\Contribution%20preparation\RAN1%23105\DSS\R1-2102138.zip) for PDSCH throughput is taken as RAN1 observation with the following revision for the note:
  + Note: Combinations 1 and 2 were agreed for evaluation. Some companies provided evaluation results for Combinations 3 and 4.

**Agreement**

The observations for multi-cell PDSCH scheduling via a single DCI to be summarized in the status report along with explanation on different combinations that were considered for submission to RAN.

RAN1 observations (from Section 2.6 of R1-2102138) for PDCCH blocking probability

On PDCCH blocking probability using a single DCI to schedule two PDSCHs on two carriers,

* 11 sources reported PDCCH blocking probability via simulation.
  + 10 sources reported reduced PDCCH blocking probability, compared to using two separate DCIs with each having 60 bits payload.
    - For the case of Combination 1 (agreed in RAN1#103-e): [2 GHz, 15 kHz SCS, 2 Tx, 2 Rx, 20 MHz carrier BW, 2-symbol CORESET with 96RBs],
      * For 108 bits DCI payload of two-cell scheduling DCI,
        + 7 sources show the reduced PDCCH blocking probability is 4%~17.8%, for number of scheduled UEs per cell per slot in range of 5~20 with 100% CA UE.
        + One source show the reduced PDCCH blocking probability is 2.4% and 9.6%, for 10 scheduled UEs per slot per cell with 10%, 50% CA UEs, respectively.
        + One source show the reduced PDCCH blocking probability is 53.9%, for 5 scheduled UEs per slot per cell with 80% CA UEs.
        + One source show the reduced PDCCH blocking probability 3.7% and 8.8% for 5 and 10 scheduled UEs per slot per cell with 100% CA UEs. UL grants were also modelled by the source assuming that 1PUSCH per UE (no UL CA) is scheduled with a 60bit DCI with a 50% probability per slot.
      * For 96 bits DCI payload of two-cell scheduling DCI,
        + 7 sources show the reduced PDCCH blocking probability is 5.1%~24%, for number of scheduled UEs per cell per slot in range of 5~20 with 100% CA UE.
        + One source show the reduced PDCCH blocking probability is 2.7% and 11.5%, for 10 scheduled UEs per slot per cell with 10%, 50% CA UEs, respectively.
        + One source show the reduced PDCCH blocking probability is 53.9%, for 5 scheduled UEs per slot per cell with 80% CA UEs.
        + One source show the reduced PDCCH blocking probability is 4.2% and 10% for 5 and 10 scheduled UEs per slot per cell with 100% CA UEs. UL grants were also modelled by the source assuming that 1 PUSCH per UE (no UL CA) is scheduled with a 60bit DCI with a 50% probability per slot.
      * For 84 bits DCI payload of two-cell scheduling DCI,
        + 7 sources show the reduced PDCCH blocking probability is 7.2%~29%, for number of scheduled UEs per cell per slot in range of 5~20 with 100% CA UE.
        + One source show the reduced PDCCH blocking probability is 3.3% and 14.2%, for 10 scheduled UEs per slot per cell with 10%, 50% CA UEs, respectively.
        + One source show the reduced PDCCH blocking probability is 61%, for 5 scheduled UEs per slot per cell with 80% CA UEs.
        + One source show the reduced PDCCH blocking probability is 4.5% and 13.9% for 5 and 10 scheduled UEs per slot per cell with 100% CA UEs. UL grants were also modelled by the source assuming that 1PUSCH per UE (no UL CA) is scheduled with a 60bit DCI with a 50% probability per slot.
      * For 72 bits DCI payload of two-cell scheduling DCI,
        + 7 sources show the reduced PDCCH blocking probability is 8.6%~32%, for number of scheduled UEs per cell per slot in range of 5~20 with 100% CA UE.
        + One source show the reduced PDCCH blocking probability is 3.8% and 16.5%, for 10 scheduled UEs per slot per cell with 10%, 50% CA UEs, respectively.
        + One source show the reduced PDCCH blocking probability is 62.6%, for 5 scheduled UEs per slot per cell with 80% CA UEs.
        + One source show the reduced PDCCH blocking probability is 4.8% and 15.7% for 5 and 10 scheduled UEs per slot per cell with 100% CA UEs. UL grants were also modelled by the source assuming that 1PUSCH per UE (no UL CA) is scheduled with a 60bit DCI with a 50% probability per slot.
    - For the case of Combination 2 (agreed in RAN1#103-e): [4 GHz, 30 kHz SCS, 4 Tx, 4 Rx, 100 MHz carrier BW, 1-symbol CORESET with 270RBs],
      * For 108 bits DCI payload of two-cell scheduling DCI,
        + 6 sources show the reduced PDCCH blocking probability is 0.8%~21.3%, for number of scheduled UEs per cell per slot in range of 5~20 with 100% CA UE.
        + One source show the reduced PDCCH blocking probability is 0.2% and 1.6%, for 10 scheduled UEs per slot per cell with 10%, 50% CA UEs, respectively.
        + One source show the reduced PDCCH blocking probability is 0% and 0.2% for 5 and 10 scheduled UEs per slot per cell with 100% CA UEs. UL grants were also modelled by the source assuming that 1PUSCH per UE (no UL CA) is scheduled with a 60bit DCI with a 50% probability per slot.
      * For 96 bits DCI payload of two-cell scheduling DCI,
        + 7 sources show the reduced PDCCH blocking probability is 0.8%~24.7%, for number of scheduled UEs per cell per slot in range of 5~20 with 100% CA UE.
        + One source show the reduced PDCCH blocking probability is 0.2% and 1.7%, for 10 scheduled UEs per slot per cell with 10%, 50% CA UEs, respectively.
        + One source show the reduced PDCCH blocking probability is 0.1% ~ 8.1%, for 5~20 scheduled UEs per slot per cell with 50% CA UEs.
        + One source show the reduced PDCCH blocking probability is 0% and 0.4% for 5 and 10 scheduled UEs per slot per cell with 100% CA UEs. UL grants were also modelled by the source assuming that 1PUSCH per UE (no UL CA) is scheduled with a 60bit DCI with a 50% probability per slot.
      * For 84 bits DCI payload of two-cell scheduling DCI,
        + 6 sources show the reduced PDCCH blocking probability is 0.8%~37.5%, for number of scheduled UEs per cell per slot in range of 5~20 with 100% CA UE.
        + One source show the reduced PDCCH blocking probability is 0.3% and 2.0%, for 10 scheduled UEs per slot per cell with 10%, 50% CA UEs, respectively.
        + One source show the reduced PDCCH blocking probability is 0% and 0.4% for 5 and 10 scheduled UEs per slot per cell with 100% CA UEs. UL grants were also modelled by the source assuming that 1PUSCH per UE (no UL CA) is scheduled with a 60bit DCI with a 50% probability per slot.
      * For 72 bits DCI payload of two-cell scheduling DCI,
        + 7 sources show the reduced PDCCH blocking probability is 0.8%~43.5%, for number of scheduled UEs per cell per slot in range of 5~20 with 100% CA UE.
        + One source show the reduced PDCCH blocking probability is 0.3% and 2.1%, for 10 scheduled UEs per slot per cell with 10%, 50% CA UEs, respectively.
        + One source show the reduced PDCCH blocking probability is 0.1% ~ 21.9%, for 5~20 scheduled UEs per slot per cell with 50% CA UEs.
        + One source show the reduced PDCCH blocking probability is 0% and 0.4% for 5 and 10 scheduled UEs per slot per cell with 100% CA UEs. UL grants were also modelled by the source assuming that 1PUSCH per UE (no UL CA) is scheduled with a 60bit DCI with a 50% probability per slot.
    - For the case of Combination 3(not agreed for evaluation but considered by some companies): [700MHz, 15 kHz SCS, 2 Tx, 2 Rx, 10 MHz carrier BW, 3-symbol CORESET with 48RBs]
      * For 108 bits DCI payload of two-cell scheduling DCI,
        + 6 sources show the reduced PDCCH blocking probability is 3.6%~24%, for number of scheduled UEs per cell per slot in range of 5~20 with 100% CA UE.
        + One source show the reduced PDCCH blocking probability is 3.0% and 10.8%, for 10 scheduled UEs per slot per cell with 10%, 50% CA UEs, respectively.
        + One source show the reduced PDCCH blocking probability is 0.1%~1.1% when the SCS is different between scheduling cell and scheduled cell, for number of scheduled UEs per cell per slot in range of 5~20 with 100% CA UE.
        + One source show the reduced PDCCH blocking probability is 8.6% and 9.5% for 5 and 10 scheduled UEs per slot per cell with 100% CA UEs. UL grants were also modelled by the source assuming that 1PUSCH per UE (no UL CA) is scheduled with a 60bit DCI with a 50% probability per slot.
      * For 96 bits DCI payload of two-cell scheduling DCI,
        + 6 sources show the reduced PDCCH blocking probability is 4.7%~34%, for number of scheduled UEs per cell per slot in range of 5~20 with 100% CA UE.
        + One source show the reduced PDCCH blocking probability is 3.3% and 12.2%, for 10 scheduled UEs per slot per cell with 10%, 50% CA UEs, respectively.
        + One source show the reduced PDCCH blocking probability is 0.6%~2.2% when the SCS is different between scheduling cell and scheduled cell, for number of scheduled UEs per cell per slot in range of 5~20 with 100% CA UE.
        + One source show the reduced PDCCH blocking probability is 9.5% and 11.3% for 5 and 10 scheduled UEs per slot per cell with 100% CA UEs. UL grants were also modelled by the source assuming that 1PUSCH per UE (no UL CA) is scheduled with a 60bit DCI with a 50% probability per slot.
      * For 84 bits DCI payload of two-cell scheduling DCI,
        + 6 sources show the reduced PDCCH blocking probability is 7.6%~34%, for number of scheduled UEs per cell per slot in range of 5~20 with 100% CA UE.
        + One source show the reduced PDCCH blocking probability is 4.0% and 16.0%, for 10 scheduled UEs per slot per cell with 10%, 50% CA UEs, respectively.
        + One source show the reduced PDCCH blocking probability is 2.8%~5.3% when the SCS is different between scheduling cell and scheduled cell, for number of scheduled UEs per cell per slot in range of 5~20 with 100% CA UE.
        + One source show the reduced PDCCH blocking probability is 11.5% and 16.3% for 5 and 10 scheduled UEs per slot per cell with 100% CA UEs. UL grants were also modelled by the source assuming that 1PUSCH per UE (no UL CA) is scheduled with a 60bit DCI with a 50% probability per slot.
      * For 72 bits DCI payload of two-cell scheduling DCI,
        + 6 sources show the reduced PDCCH blocking probability is 9.8%~34%, for number of scheduled UEs per cell per slot in range of 5~20 with 100% CA UE.
        + One source show the reduced PDCCH blocking probability is 4.5% and 18.2%, for 10 scheduled UEs per slot per cell with 10%, 50% CA UEs, respectively.
        + One source show the reduced PDCCH blocking probability is 4.1%~7.5% when the SCS is different between scheduling cell and scheduled cell, for number of scheduled UEs per cell per slot in range of 5~20 with 100% CA UE.
        + One source show the reduced PDCCH blocking probability is 12.8% and 18.8% for 5 and 10 scheduled UEs per slot per cell with 100% CA UEs. UL grants were also modelled by the source assuming that 1PUSCH per UE (no UL CA) is scheduled with a 60bit DCI with a 50% probability per slot.
    - For the case of Combination 4(not agreed for evaluation but considered by some companies): [4GHz, 30 kHz SCS, 4 Tx, 4 Rx, 40 MHz carrier BW, 2-symbol CORESET with 96RBs]
      * For 108 bits DCI payload of two-cell scheduling DCI,
        + 4 sources show the reduced PDCCH blocking probability is 2.4%~16%, for number of scheduled UEs per cell per slot in range of 5~20 with 100% CA UE.
        + One source show the reduced PDCCH blocking probability is 0.9% and 5.9%, for 10 scheduled UEs per slot per cell with 10%, 50% CA UEs, respectively.
        + One source show the reduced PDCCH blocking probability is 0.4% and 2.5% for 5 and 10 scheduled UEs per slot per cell with 100% CA UEs. UL grants were also modelled by the source assuming that 1PUSCH per UE (no UL CA) is scheduled with a 60bit DCI with a 50% probability per slot.
      * For 96 bits DCI payload of two-cell scheduling DCI,
        + 4 sources show the reduced PDCCH blocking probability is 2.7%~16.2%, for number of scheduled UEs per cell per slot in range of 5~20 with 100% CA UE.
        + One source show the reduced PDCCH blocking probability is 1.0% and 6.4%, for 10 scheduled UEs per slot per cell with 10%, 50% CA UEs, respectively.
        + One source show the reduced PDCCH blocking probability is 0.4% and 2.6% for 5 and 10 scheduled UEs per slot per cell with 100% CA UEs. UL grants were also modelled by the source assuming that 1PUSCH per UE (no UL CA) is scheduled with a 60bit DCI with a 50% probability per slot.
      * For 84 bits DCI payload of two-cell scheduling DCI,
        + 4 sources show the reduced PDCCH blocking probability is 2.8%~28%, for number of scheduled UEs per cell per slot in range of 5~20 with 100% CA UE.
        + One source show the reduced PDCCH blocking probability is 1.2% and 8.0%, for 10 scheduled UEs per slot per cell with 10%, 50% CA UEs, respectively.
        + One source show the reduced PDCCH blocking probability is 0.6% and 4.9% for 5 and 10 scheduled UEs per slot per cell with 100% CA UEs. UL grants were also modelled by the source assuming that 1PUSCH per UE (no UL CA) is scheduled with a 60bit DCI with a 50% probability per slot.
      * For 72 bits DCI payload of two-cell scheduling DCI,
        + 4 sources show the reduced PDCCH blocking probability is 2.9%~40.7%, for number of scheduled UEs per cell per slot in range of 5~20 with 100% CA UE.
        + One source show the reduced PDCCH blocking probability is 1.3% and 8.6%, for 10 scheduled UEs per slot per cell with 10%, 50% CA UEs, respectively.
        + One source show the reduced PDCCH blocking probability is 0.6% and 5.0% for 5 and 10 scheduled UEs per slot per cell with 100% CA UEs. UL grants were also modelled by the source assuming that 1PUSCH per UE (no UL CA) is scheduled with a 60bit DCI with a 50% probability per slot.
  + 1 source reported increased PDCCH blocking probability, compared to using two separate DCIs with each having 60 bits payload.
    - For the case of Combination 1 (agreed in RAN1#103-e): [2 GHz, 15 kHz SCS, 2 Tx, 2 Rx, 20 MHz carrier BW, 2-symbol CORESET with 96RBs],
      * For 108 bits DCI payload of two-cell scheduling DCI
* More detailed results and assumptions are listed in the excel tables included in R1-2102138.

RAN1 observations (from Section 2.6 of R1-2102138) for PDSCH throughput

* Note: Combinations 1 and 2 were agreed for evaluation. Some companies provided evaluation results for Combinations 3 and 4.
* 4 sources, reported PDSCH throughput via system level simulation and 2 sources reported PDSCH throughput via theoretical analysis, compared to using two separate DCIs with each having 60 bits payload.
  + For 108 bits DCI payload of two-cell scheduling DCI,
    - 1 source show the gain of PDSCH throughput is 6.69 ~8.93%, for per cell UE number in range of 10~20 with 100% DL CA UE only, full buffer, no common message scheduling, and with assumptions of PDCCH blocking probability reduction implemented for PDCCH and PDSCH multiplexing (i.e. SU/MU-MIMO) implemented for PDSCH reception.
    - 1 source show the gain of PDSCH throughput is 0.74% ~1.42% for combination4, 3.02 ~3.12% for combination3, 1.27% ~1.56% for combination2, 1.80% ~2.23% for combination1,for per cell UE number in range of 10~20 with 100% CA UE (no UL DCI, no single-cell scheduling, no CSS) and full buffer traffic model, with assumptions of utilizing saved CORESET RBs for PDSCH transmission.
    - 1 source show the gain of PDSCH throughput is <1%, for 10 UEs per cell UE with 100% CA UE and full buffer traffic model without assumptions of utilizing saved CCE resources for PDSCH transmission.
  + For 96 bits DCI payload of two-cell scheduling DCI,
    - 1 source show the gain of PDSCH throughput is 7.89%~10.92% with similar assumptions as provided for PDCCH payload of 108 bits.
    - 1 source show the gain of PDSCH throughput is -0.31%~0.94% for combination4, 3.02%~3.11% for combination3, 1.90%~2.32% for combination2, 2.31%~2.44% for combination1, for per cell UE number in range of 10~20 with 100% CA UE (no UL DCI, no single-cell scheduling, no CSS) and full buffer traffic model, with assumptions of utilizing saved CORESET RBs for PDSCH transmission
    - 1 source shows the gain of PDSCH throughput is 3.0%~8.1% for combination1 for per cell UE number of 10 with 100% CA UEs and full buffer traffic model, with assumptions of utilizing saved CORESET RBs for PDSCH transmission
    - 1 source shows the gain of PDSCH throughput is 8.2%~22.4% for combination1, 27.3%~63.2% for combination3 for per cell UE number of 10 with 100% CA UEs and FTP 3 traffic model with packet size = 20Kbytes (combination1) and 12Kbytes (combination3), with assumptions of utilizing saved CORESET RBs for PDSCH transmission
  + For 84 bits DCI payload of two-cell scheduling DCI,
    - One source shows the gain of PDSCH throughput is -13.4%~-8.7%, for 10 UEs per cell 100% CA UEs and full buffer traffic model without assumptions of utilizing saved CCE resources for PDSCH transmission and with shared FDRA/TDRA for two scheduled PDSCHs.
    - 1 source shows the gain of PDSCH throughput is 3.0%~8.1% for combination1 for per cell UE number of 10 with 100% CA UEs and full buffer traffic model, with assumptions of utilizing saved CORESET RBs for PDSCH transmission
    - 1 source shows the gain of PDSCH throughput is 8.2%~22.4% for combination1, 29.0%~68.4% for combination3 for per cell UE number of 10 with 100% CA UEs and FTP 3 traffic model with packet size = 20Kbytes (combination1) and 12Kbytes (combination3), with assumptions of utilizing saved CORESET RBs for PDSCH transmission
  + One source shows there is no gain for 20MHz BW even for only PDSCH scheduling on 2 cells all the time (no single-cells scheduling, no UL, no CSS) and no loss due to UL DCI padding, with assumption of 84 or 132 bits of the two-cell scheduling DCI by applying the Shannon capacity formula to the CCE savings and normalizing by the total number of time-frequency resources per slot for the indicated BW of the scheduling cell.
  + One source shows there is <2.5% gain for Combination 1 and no gain for Combination 2, with assumption that all saved PDCCH CCE resources can be reused for PDSCH, no scheduling flexibility is lost due to two-cell DCI, and assumption that 50% slots can benefit from using two-cell scheduling DCI. 96 bits payload size for the two-cell scheduling DCI is assumed. UL grants were also modelled by the source assuming that 1PUSCH per UE (no UL CA) is scheduled with a 60bit DCI with a 50% probability per slot.
* More detailed results and assumptions are listed in the excel tables included in R1-2102138.

## Agreements made in RAN1#103-e

Agreements:

Further study with below simulation assumptions:

Simulation scenarios:

* For two-cell scheduling via a single DCI, PDCCH transmitted on a first cell schedules one PDSCH on the first cell and another PDSCH on a second cell.
* For single-cell scheduling (baseline), one PDCCH transmitted on a first cell schedules one PDSCH on the first cell via self-scheduling and another PDCCH transmitted on the first cell schedules another PDSCH on a second cell via cross-carrier scheduling.
  + Companies can optionally compare to the case of PDCCH transmitted on each of the two cells via self-scheduling. In this case, company should provide details on how to calculate the PDCCH blocking rate.

Simulation assumptions on carrier frequency, SCS, antenna configuration, carrier bandwidth as well as CORESET configuration

* Combination 1: 2 GHz, 15 kHz SCS, 2 Tx, 2 Rx, 20 MHz carrier BW, 2-symbol CORESET with 96RBs
* Combination 2: 4 GHz, 30 kHz SCS, 4 Tx, 4 Rx, 100 MHz carrier BW, 1-symbol CORESET with 270RBs
* [Combination 3: 700MHz, 15 kHz SCS, 2 Tx, 2 Rx, 10 MHz carrier BW, 3-symbol CORESET with 48RBs]
* [Combination 4: 4GHz, 30 kHz SCS, 4 Tx, 4 Rx, 40 MHz carrier BW, 2-symbol CORESET with 96RBs]

Payload size of two-cell scheduling DCI (excluding CRC):

* 60 for single-cell scheduling DCI (baseline).
* 72/84/96/108 for two-cell scheduling DCI.
* Companies are encouraged to report how the values are obtained, e.g., via separate or shared fields in DCI format.

Target BLER for two-cell scheduling DCI: 1% (baseline), 0.5%(optional)

* ~~Option 1: 1%.~~
* ~~Supported by OPPO, vivo, Nokia, Qualcomm, CATT, Ericsson, Huawei, Lenovo, Intel, MediaTek~~
* ~~Option 2: 0.5%.~~
* ~~Supported by Samsung, LG~~

Regarding the CCE-to-REG mapping, based on the agreed interleaved CCE-to-REG mapping, whether to adopt non-interleaved CCE-to-REG mapping is up to the proponent.

Agreements:

* Further study with below simulation assumptions:

                     Table 2: System level simulation assumptions

|  |  |
| --- | --- |
| **Parameters** | **Values** |
| Carrier frequency | For scheduling cell, follow agreed link level simulation assumptions  For scheduled cell, consider 700MHz/2GHz with 10/20MHz BW (LTE overhead on DSS carrier can be optionally provided, up to proponent) |
| SCS |
| Simulation bandwidth |
| BS antenna height | 25 m |
| UE height | 1.5m |
| TRP transmit power | 46 dBm for 10MHz |
| Scenario | Urban Macro |
| ISD | 500m |
| TRP antenna configuration | (M,N,P,Mg,Ng;Mp,Np)= (1,2,2,1,1;1,1) for 700MHz  (M,N,P,Mg,Ng;Mp,Np)= (2,8,2,1,1;1,1) for 2GHz  (M,N,P,Mg,Ng;Mp,Np)= (8,4,2,1,1;1,1) for 4GHz |
| UE antenna configuration | (M,N,P,Mg,Ng;Mp,Np)= (1,1,2,1,1;1,1) for 700MHz/2GHz  (M,N,P,Mg,Ng;Mp,Np)= (1,2,2,1,1;1,1) for 4GHz |
| Device deployment | 80% indoor, 20% outdoor |
| UE speeds of interest | Indoor users: 3km/h |
| Outdoor users (in-car): 30 km/h |
| BS noise figure | 5 dB |
| BS antenna element gain | 8 dBi |
| UE noise figure | 9 dB |
| Thermal noise level | -174 dBm/Hz |
| Traffic | Full Buffer(baseline), FTP model 1 or 3 up to company |
| Macro sites | 19 |
| Number of UEs per cell | 10/15/20 UEs |
| Downtilt | 102° |
| Minimum BS to UE distance | 35m |

Agreements:

Further study multi-cell PDSCH scheduling via a single DCI with below simulation assumptions:

                                     Table 1: Link level simulation assumptions

|  |  |
| --- | --- |
| **Parameters** | **Values** |
| Carrier frequency | Option 1:  Inter-band CA (700MHz + 4GHz)  Intra-band CA (2GHz)    Option 2:  Only 4GHz is considered |
| SCS | 15 kHz for 700MHz/2GHz  30 kHz for 4GHz |
| Bandwidth | Option 1:  Baseline: PCell 10MHz + SCell 10/40MHz  Optional: PCell 20MHz + SCell 20/40/100MHz    Option 2:  Baseline: Scheduling cell 100 MHz  Optional: Scheduling cell 20 MHz |
| Channel model | TDL-C |
| Delay spread | 300 ns |
| Number of symbols for CORESET | [1], 2 or 3 |
| CORESET BW (contiguous PRB allocation) | 24/48/96 RBs depending on the bandwidth |
| CCE-to-REG mapping | Interleaved, [non-interleaved] |
| REG bundle size | 6 |
| Interleaver size | 2 |
| DCI payload size (excluding CRC) | Single PDSCH scheduling: 60 bits as baseline payload size  Multi-cell PDSCH scheduling: 72/84/96/104 bits |
| BLER target for multi-cell scheduling DCI | Option 1: 1%  Option 2: 0.5% |
| Number of BS antennas | 2 Tx for 700MHz/2GHz carrier frequency  4 Tx for 4GHz |
| Number of UE antennas | 2 Rx for 700MHz/2GHz carrier frequency  4 Rx for 4GHz carrier frequency |
| Modulation | QPSK |
| Channel coding | Polar code |
| UE speed | 3km/h |
| Aggregation level | 1/2/4/8/16 |
| Tx Diversity | One port precoder cycling |

Note 1: For two-cell scheduling via a single DCI, PDCCH transmitted on SCell schedules one PDSCH on the SCell and another PDSCH on PCell.

Note 2: For comparison, for single-cell scheduling, one PDCCH transmitted on SCell schedules one PDSCH on the SCell via self-scheduling and another PDCCH transmitted on the SCell schedules another PDSCH on PCell via cross-carrier scheduling.

Further discussion which rows are applicable to the scheduling cell/the scheduled cell for PDCCH

## Agreements made in RAN1#102-e

Agreements:

* Following scheduling combinations are allowed/not allowed when cross-carrier scheduling from an SCell to PCell/PSCell is configured
  1. self-scheduling on PCell/PSCell is allowed
  2. cross-carrier scheduling from PCell/PSCell to another SCell is not allowed
  3. self-scheduling on the ‘SCell used for scheduling PCell/PSCell’ is allowed
  4. cross-carrier scheduling from the ‘SCell used for scheduling PCell/PSCell’ to another serving cell is allowed
  5. cross-carrier scheduling from another serving cell to the ‘SCell used for scheduling PCell/PSCell’ is not allowed
* FFS: Search space and DCI format handling for the allowed cases above

Agreements:

* Configuring 2 or more Scells to schedule the PCell/PSCell is not allowed

Agreements:

* For the study on single DCI scheduling PDSCH on two cells
  + Consider the following scenarios as baseline for evaluation
    - UE configured with Inter-band CA with PCell and an SCell
      * PCell for the UE is operated on a DSS carrier (i.e., same carrier is also used for serving LTE users)
      * Case 1: Different SCS for PCell and SCell
      * Case 2: Same SCS for PCell and Scell
  + Additional scenarios can also be evaluated, e.g. as below
    - Intra-band CA case with multiple serving cells having same SCS (all cells operated on non DSS carriers)
    - Inter-band CA case with PCell and more than one SCell (at least the SCells are operated on non DSS carriers)
    - Note: other combinations not precluded
* Note: Further details of evaluation framework (including carrier BW, slot format etc.) to be discussed in next stage