**3GPP TSG RAN WG1 Meeting #104-e R1-21XXXXX**

**e-Meeting, January 25th – February 5th, 2020**

**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:

|  |
| --- |
| 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, evaluation assumptions and evaluation results are summarized. Companies’ views on whether to support this feature are also summarized at the end of Section 2. Based on majority companies’ views, some proposals 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.

## Simulation assumptions

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 |

## Simulation results

Based on agreed simulation assumptions, total 13 companies provide simulation results in terms of CCE saving, PDCCH blocking probability and PDSCH throughput.

### CCE saving and PDCCH blocking probability

Since NR transmission can’t use REs occupied by LTE CRS and LTE PDCCH region on a carrier shared with LTE, NR PDCCH capacity on this shared carrier is limited especially when this shared carrier is configured as PCell for NR. The insufficient NR PDCCH capacity on the NR PCell will lead to system performance degradation especially when more NR devices are camped on the NR PCell.

Supporting cross-carrier scheduling from NR SCell to NR PCell results in requiring additional PDCCH capacity of the scheduling SCell due to the need for self-scheduling on the SCell as well cross-carrier scheduling on the (shared carrier) PCell. Thus, the PDCCH capacity on the SCell may be a potential issue when a large number of UEs are configured on the SCell or the SCell is not configured with a large enough bandwidth. This issue can be addressed by allowing a single DCI on one carrier to schedule PDSCHs on two carriers. In detail, two PDSCHs on two carriers are scheduled by a single DCI format, which saves PDCCH scheduling overhead compared to scheduling two PDSCHs on two carriers by two DCI formats. Since the number of required PDCCHs is reduced, many companies observe the PDCCH blocking probability is reduced.

On the other hand, in inter-band CA, the payload size of the single DCI increases significantly when it schedules two PDSCHs on two carriers due to different channel conditions. Some companies think it may increase PDCCH blocking rate since a high AL is needed for this DCI. For intra-band CA, some companies think the payload size of the single DCI does not increase significantly by sharing many fields of the DCI.

Regarding PDCCH blocking probability, companies’ views are summarized as below:

|  |  |
| --- | --- |
| Company | Key Proposals/Observations |
| ZTE | Observation 1: For inter-band CA case,   In case of 700M and 4G, the average gain of PDCCH blocking rate for DCI size 72 bits, 84 bits 96 bits and 108 bits of the one-to-two scheduling DCI is about 5.7%, 4.0%, 1.4% and 0.6%, respectively.   In case of 700M and 2G, the average gain of PDCCH blocking rate for DCI size 72 bits, 84 bits 96 bits and 108 bits of the one-to-two scheduling DCI is about 11.1%, 9.3%, 6.1% and 4.8%, respectively.  Observation 3: For intra-band (2GHz) CA case, the average gain of PDCCH blocking rate for DCI size 72 bits, 84 bits, 96 bits and 108 bits of the one-to-two scheduling DCI is about 9.5%, 7.5%, 5.6% and 4.6%, respectively. |
| 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. |
| Huawei, HiSilicon | Observation 1: From link level evaluations, for one PDCCH scheduling PDSCH(s) on two cells, with respect to different PDCCH payloads in the range of 108~72 bits, significant number of CCEs can be saved for all evaluated scenarios   * 27.74%~42.95% average CCE saving ratio for Combination 1 * 23.53%~45.02% average CCE saving ratio for Combination 2 * 21.53%~41.89% average CCE saving ratio for Combination 3 * 21.3%~43.29% average CCE saving ratio for Combination 4   Observation 2: Single DCI scheduling PDSCH(s) on two cells can reduce the PDCCH blocking probability obviously. |
| CATT | Based on the results in Figure 1 – Figure 4 and Table 5 – Table 8, we can have the following observations:   * Multi-cell scheduling via a single DCI can significantly increase the PDCCH capacity. In the other words, possibility of PDCCH blocking is reduced remarkably.   + The benefits harvested from DSS-DCI in terms of PDCCH capacity increases as the ratio of DSS-UE goes up * The benefits harvested from DSS-DCI in terms of PDCCH capacity is impacted on the DCI design, i.e. the smaller size the DSS-DCI has, the more significant benefit can be got.   + Even the size of the DSS-DCI is doubled compared to the legacy-DCI, PDCCH capacity can still be enhanced. The improvement comes from:     - The 24 bits CRC can be saved.     - Even the payload is doubled, the requirement on large aggregation level such as 8 and 16 still keeps a low level. |
| vivo | Observation 1. Compared with using single-cell-DCI, a joint-DCI scheduling two PDSCHs on two cells brings more than  - 33.09% CCE saving for combination 1,  - 28.13% CCE saving for combination 2,  - 32.59% CCE saving for combination 3,  - 18.14% CCE saving for combination 4,  and the CCE saving gain becomes more significant if the compression rate of joint-DCI size increases.  Observation 2. With the same CORESET bandwidth, a joint-DCI with size (excluding CRC) =108 bits brings around  - 8.22%~8.84% reduction in PDCCH blocking rate for combination1,  - 5.2%~8.05% reduction in PDCCH blocking rate for combination2,  - 6.49%~9.07% reduction in PDCCH blocking rate for combination3,  - 2.37%~5.66% reduction in PDCCH blocking rate for combination4  compared with using single-cell-DCI, and the reduction in PDCCH blocking rate becomes more significant if the joint-DCI size decreases.  Proposal 1. The design of joint-DCI should achieve a good trade-off between system capacity improvement due to CCE saving/PDCCH blocking rate reduction and the spectrum efficiency loss due to the coarser scheduling granularity and degraded scheduling flexibility. |
| Lenovo, Motorola Mobility | Observation 1: The payload size of a single DCI scheduling two PDSCHs on two carriers can be in a range of 80~110 and further reduced if some fields are configured with less bits.  Observation 2: Compared to a single DCI scheduling a single PDSCH, the payload size of a single DCI scheduling two PDSCHs on two carriers needs to be increased about 21~54%.  Observation 3: Compared to two DCIs scheduling two PDSCHs, the payload size of a single DCI scheduling two PDSCHs on two carriers can save 23% ~ 39% overhead.  Observation 4: Two-cell scheduling DCI has lower PDCCH blocking rate compared with using two single-cell scheduling DCIs. |
| Intel | Observation 2: Based on the required SINR values and geometry curves obtained by LLS and SLS   * The ratio of CCE saving is about 20~40%; * The reduced PDCCH blocking ratio is observed. |
| Samsung | Observation 7: For a DCI format scheduling two PDSCH receptions where only fields not affecting scheduling are not duplicated, the blocking probability is larger than for one DCI format scheduling one PDSCH reception. |
| Nokia, NSB | Observation 5:  The Average PDCCH Blocking probabilities for interleaved and non-interleaved cases are presented in Figure 4 and Figure 5. From these figures we can make the following observations:   1. As the number of users are increasing it is evident that the blocking probability is also increasing. 2. In Interleaved case for DCI size 60/72/84/96 bits the blocking probability curves are very similar while for Non-Interleaved case the differences are slightly larger. 3. For DCI size 108, the blocking probability is slightly higher in case of Non-Interleaved vs Interleaved. 4. As observed in the figures, the blocking probability increases with the number of users, the blocking probability for scheduling X DCIs with 108 bit Multi-DCI scheduling will be significantly lower than the blocking probability for 2\*X DCIs with 60 bit DCI, regardless of Interleaved or non-interleaved mapping. 5. For the given scenario of 2GHz, only two DCIs can be supported per PDCCH with below 1% blocking probability for any DCI size. |
| InterDigital | Observation 1: Supporting a single PDCCH scheduling multiple cells enables efficient spectrum sharing and reduces the downlink control channel overhead on the shared spectrum.  Observation 2: PDCCH blocking probability and CCE utilization can be reduced by using a single DCI scheduling PDSCH on two cells. |
| Qualcomm | Observation 1: The overhead saving gain from multi-cell PDSCH scheduling compared to single-cell PDSCH scheduling in inter-band CA for DSS scenario is mainly comes from the omission of 24-bit CRC. In intra-band CA scenario, higher gain would be achievable by compressing some DCI fields.  Observation 2: The PDCCH blocking probability improvement from multi-cell PDSCH scheduling compared to single-cell PDSCH scheduling highly depends on whether the DCI size can be compressed aggressively. |
| Ericsson | Observation 3   * For scenario 1 (i.e., 20MHz carrier at 2GHz used for scheduling PCell PDSCH/PUSCH on another low-band DSS carrier),   + in slots where PDSCH is scheduled on both cell1 and cell 2, mc-DCI can achieve similar blocking performance as baseline case with reduced CCE allocation. The amount of possible CCE reduction depends on loading, i.e., 8 CCEs for low load and smaller for higher loads. If CCE allocation is reduced any further, performance of mc-DCI is worse.   + Assuming 50% of slots have two-PDSCH scheduling with cell1 scheduling PDSCH on both cell1 and cell2 (optimistic assumption for scenario 1 if one of the scheduled carriers is shared with LTE), and 10 symbols available for data scheduling on scheduling cell (2 DMRS symbols), an overhead reduction of < 2.5% is expected with other optimistic assumptions that rate-matching of PDSCH around PDCCH can reclaim all the saved resources (which is unlikely when there are other DCIs in the Coreset), and that there is no performance loss due to lower flexibility when scheduling with mc-DCI. Under realistic assumptions, no gains are expected.   Observation 4   * For scenario 2 (i.e., 100MHz mid-band 4GHz carrier used for scheduling PCell PDSCH/PUSCH on a low-band DSS carrier),   + using mc-DCI is not expected to provide performance gains as the blocking performance for scheduling up to 10 UEs is close to zero even for baseline case of two legacy DCIs.   Observation 5   * Evaluations indicate that single DCI scheduling PDSCH on two cells (mc-DCI) provides marginal or no performance gains. |

### PDSCH throughput improvement

For one DCI scheduling two PDSCHs on two carriers, it is expected that CCE resources are saved compared to using two DCIs scheduling two PDSCHs. The saved frequency resources can be scheduled for PDSCH transmission for improving PDSCH throughput.

On the other hand, if most of the DCI fields are shared between two carriers, the PDCCH blocking probability is reduced while the scheduling flexibility may be restricted when same TDRA/FDRA field is shared for the two carriers. A trade-off between the DCI payload size and the PDSCH throughput is needed.

Regarding PDSCH throughput, companies’ views are summarized as below:

|  |  |
| --- | --- |
| Company | Key Proposals/Observations |
| ZTE | Observation 2:  For inter-band (700MHz + 4GHz) CA case,   * In case of 108 bits of one-to-two scheduling DCI, the throughput is similar as the baseline. * In case of 84 bits of one-to-two scheduling DCI, the throughput is reduced by 13.4% compared with the baseline.   For inter-band (700MHz + 2GHz) CA case,   * In case of 108 bits of one-to-two scheduling DCI, the throughput is similar as the baseline. * In case of 84 bits of one-to-two scheduling DCI, the throughput is reduced by 9.9% compared with the baseline.   Observation 4: For intra-band (2GHz) CA case,   * In case of 108 bits of one-to-two scheduling DCI, the throughput is similar as the baseline. * In case of 84 bits of one-to-two scheduling DCI, the throughput is reduced by 8.7% compared with the baseline. |
| Huawei, HiSilicon | Observation 3: For the two carriers of combination 1 and combination 3, the single DCI scheduling PDSCHs on two carriers can achieve  − up to 8.29% throughput gain when payload size of single DCI is 108bits  − up to 10% throughput gain when payload size of single DCI is 96bits.  Observation 4: For two carriers of combination 1 and combination 1, the single DCI scheduling PDSCHs on two carriers can achieve  − up to 8.93% throughput gain when payload size of single DCI is 108bits  − up to 10.88% throughput gain when payload size of single DCI is 96bits.  Observation 5: The throughput gain by joint scheduling increases as the LTE overhead/traffic load increases on a DSS carrier.  Observation 6: PDCCH coverage is not a concern with single DCI scheduling PDSCH(s) over two cells. |
| vivo | Observation 3. Joint-DCI requires fewer CORESET RBs to achieve the same scheduling opportunities as single-cell-DCI, thus gNB can provide a CORESET with less PRBs for joint-DCI scheduling than single-cell-DCI scheduling. These saved RBs can be reused for PDSCH to improve throughput.  Observation 4. Compared with using single-cell-DCI, joint-DCI brings around - 24~27 RB reduction in CORESET BW and <=3.24% theoretical throughput gain for combination1,  - 42~54 RB reduction in CORESET BW and <=3.32% theoretical throughput gain for combination2, - 12~16 RB reduction in CORESET BW and <=3.66% theoretical throughput gain for combination3, - 6~12 RB reduction in CORESET BW and <=4.79% theoretical throughput gain for combination4.  Observation 5. Joint-DCI with size=96bits~108 bits can bring - <=2.44% throughput gain compared with single-cell-DCI for combiantion1 in practical scenarios - <=2.32% throughput gain compared with single-cell-DCI for combiantion2 in practical scenarios - <=3.12% throughput gain compared with single-cell-DCI for combiantion3 in practical scenarios compared with single-cell-DCI.  Observation 6. When the number of UE is 10, joint-DCI with size=96bits~108 bits can bring <=1.42% throughput gain compared with single-cell-DCI for combiantion4 in practical scenarios. However, it can also bring 0.2%~0.31% throughput loss if the number of UE increases to 15/20. |
| MediaTek | Observation 1: In both full-buffer and FTP traffic, a UE with 2-cell CA is not always scheduled with PDSCHs over 2 cells whenever there is data packet   * Full-buffer traffic (2GHz)   + 1 scheduled cell: 70% of slots   + 2 scheduled cells: 30% of slots * FTP traffic with a packet size of 20Kbytes (2GHz)   + 1 scheduled cell: 30% of slots   + 2 scheduled cell: 70% of slots   Observation 2: Compared to legacy scheme, scheme #1/2/3 provide non-negligible UE throughput gain in both full-buffer and FTP traffic  Observation 3: For FTP traffic, the mean/cell-edge UE throughput gain for 700MHz is larger than that for 2GHz due to larger RU reduction resulted from CORESET overhead reduction  Observation 4: DCI aggregation for cross-carrier scheduling provides higher cell-edge UE throughput gain than mean UE throughput gain  Observation 5: Compared to scheme #1/2 (i.e. 1-stage DCI aggregation), scheme #3 (i.e. 2-stage DCI aggregation) provides larger mean and cell-edge UE throughput gain for 700MHz |
| Samsung | Observation 1: The maximum throughput gain for Combination 1 is 1.07%.  Observation 2: The maximum throughput gain for Combination 2 is 0.084%.  Observation 3: The scenario for Combination 3 is atypical and problematic and does not affect conclusions for use of a DCI format scheduling PDSCH receptions on two cells.  Observation 4: For a DCI format scheduling PDSCH receptions on two cells (DCI format X):   1. Residual resources in a CORESET cannot be used for PDSCH if the PDCCH is not the only one in the CORESET. 2. Overhead increase occurs as either DCI format 0\_1 needs to be size-matched with DCI format 1\_1, or DCI format X needs to also be used for scheduling PDSCH reception on only one cell.   Observation 5: Joint applicability on two cells for a field serving to maximize throughput per cell would result in throughput loss that is at least an order of magnitude larger than any gain from saving a few bits in the DCI format.  Observation 6: Contiguous spectrum below 2 GHz is typically limited to less than 20 MHz and there is no need to divide that spectrum among multiple cells. |

### UE blind detection reduction and power saving

Using a single DCI format scheduling two PDSCHs on two carriers can save UE’s power consumption since UE needs to monitor the DCI in the search space of only one carrier where the DCI format is transmitted. This is especially true when the scheduling cell is configured with small bandwidth and the scheduled cell has ultra-wide carrier.

Regarding UE power saving, companies’ views are summarized as below:

|  |  |
| --- | --- |
| Company | Key Proposals/Observations |
| Huawei, HiSilicon | Observation 10: A single PDCCH scheduling PDSCH over two cells can save up to 6.67%~15% power consumption comparing with two separate PDCCHs for scheduling.  Observation 11: Using single DCI scheduling multi-carriers can achieve more gain for the scenario that multi-TRP and/or mini-slot based CORESET is configured on the scheduled cell. |
| Lenovo, Motorola Mobility | Observation 5: Using single DCI scheduling two PDSCHs on two carriers can save UE’s power consumption. |
| Nokia, NSB | Observation 2: Two-cell DCI format may reduce UEs monitoring burden as UE needs to monitor search-space set(s) of only single scheduling cell compared to R16, given that design is based on DCI format 1\_1. |

### Whether to support multi-cell PDSCH scheduling by single DCI?

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

**Company views:**

|  |  |
| --- | --- |
| **Company** | **Key Proposals/Observations** |
| ZTE | Observation 11: For 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.   Observation 12: SCell-schedule-PCell in DSS WI and multi-PDSCH scheduling with one single DCI in 52.6GHz-71GHz WI can effectively resolve the PDCCH capacity issue on PCell i.e. usually a shared carrier in DSS scenario, which is the major issue to be addressed in this WI.  Proposal 1: RAN1 further discusses the necessity, potential gain, open issues and possibility of timely completion of single DCI scheduling two PDSCHs on two carriers. |
| OPPO | Proposal 1: Considering performance from CCE saving ratio and PDCCH blockage reduction, One-to-two scheduling should be supported. |
| CATT | 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 network flexibility. |
| 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. |
| ASUSTeK | Proposal 1: NR DSS supports PDCCH scheduling PDSCHs on two cells using a single DCI |
| Samsung | Proposal: A DCI format that schedules PDSCH receptions on two cells is not introduced. |
| Apple | Proposal 1: We do not observe enough justification and motivation to allow single DCI to schedule PDSCH on multiple cells. |
| Lenovo, Motorola Mobility | Proposal 1: Support using a single DCI to schedule two PDSCHs on two cells.  Proposal 2: Further study payload size reduction for the two-cell scheduling DCI. |
| MediaTek | Proposal 1: Conclude in RAN1 that multi-cell PDSCH scheduling via single DCI provides significant system benefits in terms of UE throughput, UE PDCCH blind decoding complexity and UE power consumption for PDCCH blind decoding.  Proposal 2: Continue to work on detailed design of multi-cell PDSCH scheduling via single DCI with the following design considerations.   * PDCCH blind decoding complexity is not worse than Rel-16 * Scalable DCI size based on the number of scheduled cells * Switch of same/different TDRA/FDRA across the scheduled cells * Forward compatibility to CA with more than 2 cells |
| Nokia, NSB | Proposal 1: Support multi-cell DCI in R17, focus on multiple SCell (2 or more) with the same/similar carrier size and SCS first. |
| InterDigital | Proposal 1: Support a single DCI to schedule two PDSCH in different cells. |
| Qualcomm | Proposal: Conclude not to support multi-cell PDSCH scheduling via a single DCI as part of Rel.17 DSS work item. It can be discussed in future potential work items. |
| NTT DOCOMO | Proposal 1:   * The following both scheduling options should be supported if multi-cell PDSCH scheduling via single DCI is supported.   + Option.1: cross-carrier and self-carrier scheduling PDSCHs via a single DCI   + Option.2: only cross-carrier scheduling PDSCHs via a single DCI |
| Apple | Not to support single DCI to schedule two PDSCH in different cells |

### Summary of observations

For this agenda, total 18 contributions are submitted, and 13 contributions provide simulation results. Basically, there are three metrics evaluated according to the agreed simulation assumptions, CCE saving, PDCCH blocking probability and PDSCH throughput.

On CCE saving by using a single DCI to schedule multiple PDSCHs on multiple carriers, simulation results are summarized below:

* 7 companies [OPPO, Huawei, HiSilicon, Intel, InterDigital, vivo, MediaTek, CATT] observe reduced CCE consumptions via simulation.
  + OPPO: CCE saving ratio is more than 10% for any DCI size even CA ratio is not large.
  + Huawei, HiSilicon: for DCI size in range of 108~72 bits,
    - 27.74%~42.95% average CCE saving ratio for Combination 1
    - 23.53%~45.02% average CCE saving ratio for Combination 2
    - 21.53%~41.89% average CCE saving ratio for Combination 3
    - 21.3%~43.29% average CCE saving ratio for Combination 4
  + Intel: The ratio of CCE saving is about 20~40%.
  + Vivo: joint-DCI scheduling brings more than
    - 33.09% CCE saving for combination 1,
    - 28.13% CCE saving for combination 2,
    - 32.59% CCE saving for combination 3,
    - 18.14% CCE saving for combination 4,
  + MediaTek: for Combination 1, saving rate is 21.3% for 84 bits DCI, 20.6% for 96 bits DCI.
  + CATT: for a DSS-DCI with payload size 60 bits – 108 bits,
    - 28% - 45% average CCE saving ratio for combination 1
    - 22.5%- 45% average CCE saving ratio for combination 2
    - 26.4% - 41.7% average CCE saving ratio for combination 3
    - 21.1% - 42.1% average CCE saving ratio for combination 4

On PDCCH blocking probability using a single DCI to schedule multiple PDSCHs on multiple carriers, simulation results are summarized below:

* 12 companies [OPPO, Huawei, HiSilicon, Intel, InterDigital, CATT, vivo, Nokia, NSB, Lenovo, Motorola Mobility, Qualcomm] observe decreased PDCCH blocking probability via simulation.
* 2 companies [ZTE, Ericsson] observed marginal performance gain in PDCCH blocking.
* 1 company [Samsung] observe higher PDCCH blocking compared to two DCIs scheduling two PDSCHs.

On PDSCH throughput, simulation results are summarized below:

* 4 companies [Huawei, HiSilicon, vivo, MediaTek] observe non-negligible PDSCH throughput gain via simulation.
  + Huawei, HiSilicon: 8~10% throughput gain for 108bits DCI or 96bits DCI.
  + Vivo: 2.32~3.12% throughput gain for 96bits DCI or 108bits DCI for combination 1/2/3, 1.42% throughput gain for combination4, but if the number of UE increases to 15 or 20, using single DCI to schedule multiple PDSCH may bring 0.2%~0.31% throughput loss for combination4 as the loss caused by increased scheduling granularity cannot be compensated by throughput gain brought by the saved PDCCH resources.
  + MediaTek: For 96bits DCI, 16.7%/32.7% mean/cell-edge UE throughput gain for 2GHz and 29~34%/63~100% mean/cell-edge UE throughput gain for 700MHz.
* 1 company [Samsung] observe marginal throughput gain 1.07% for Combination 1 and 0.084% for Combination 2 for 108bits DCI via estimation.
* 1 company [ZTE] observe 13.4 or 8.7% loss for inter-band case and intra-band case for 84 bits DCI via simulation.

On UE blind detection reduction and power saving, companies’ simulation results and views are summarized below:

* 6 companies [Huawei, HiSilicon, Lenovo, Motorola Mobility, Nokia, NSB] observe UE power saving by using a single DCI to schedule multiple PDSCHs on multiple carriers.
  + Huawei, HiSilicon: save up to 6.67%~15% power consumption.

Companies’ views on whether to support multi-cell scheduling via a single DCI are summarized below:

* Support (12): OPPO, CATT, Huawei, HiSilicon, ASUSTeK, Lenovo, Motorola Mobility, MediaTek, Nokia, NSB, InterDigital, DoCoMo, Intel
* FFS (2): ZTE, LG
* Not support (3): Samsung, Apple, Qualcomm, Ericsson

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

|  |  |
| --- | --- |
| **Company** | **View** |
| Intel | Based on our evaluation results on CCE saving and blocking ratio reduction, we support to introduce multi-cell scheduling. We think it is enough to support one DCI to schedule transmission on up to two cells. |
| Qualcomm | The CCE saving ratio is not necessary. It is important to observe the real gain(s) the solution offers. In this sense, the observations should be made based on PDCCH blocking probability and DL throughput.  Regarding PDCCH blocking probability, it should be clear for which scenario what amount of gain can be achieved (at least roughly). Note that the operation point of PDCCH blocking probability should be not higher than 10%, which should be taken into account for the discussion.  Regarding DL throughput, there should be a trade-off between the gain and pain; there could be an improvement through PDCCH overhead reduction while could be a degradation due to lower resource allocation granularity because of DCI field compression. From the evaluation results, three companies (Huawei, HiSilicon, MediaTek) observed substantial (8% or higher) gains while three companies (vivo, Samsung, ZTE) observed little (less than 4%) gains or degradation. This should be stated. By the way, on the MediaTek’s result, we wonder why 63~100% mean/cell-edge UE throughput gain is achievable by just reducing PDCCH overhead?  Regarding UE power saving, the gain would be achievable if the UE does not monitor a DCI format for single-cell PDSCH scheduling when the UE is configured with monitoring a DCI for multi-cell PDSCH scheduling. This condition should be captured. |
| CATT | Add our observation on CCE saving ratio from our simulation results in the above.  We share the same view with Intel. The benefits of multi-cell scheduling are obvious in several aspects.  From our understanding, the CCE saving ratio is meaningful although it may not be so practical as mentioned by Qualcomm. In theory, gNB can use each available CCE for PDCCH transmission considering the number of UEs staying in the cell is large enough. It can reflect the PDCCH capacity with exclude the bias caused by configuration and simulation. |
| ZTE | Note: Our tdoc has been updated to R1-2101789, which further includes the simulation resultsof 700MHz+2GHz CA. We have added the updated observations in Section 2.2.1 and 2.2.2 of this FL summary.  First of all, CCE saving ratio is not necessary because only parts of the saved CCE can be reused for PDCCH and PDSCH, which can already be reflected via PDCCH blocking rate and PDSCH throughput, respectively.  Regarding power saving, from our perspective, the potential gain observed by companies is from reduced BD/CCE limits. However, it is still not clear whether the BD/CCE budget can be reduced subject to further discussion.  Thus, overall, from our perspective, we should focus on **PDCCH blocking rate and PDSCH throughput**.  Regarding PDCCH blocking rate, most of companies simulated different DCI sizes. We can try to summarize and make some observations regarding the detailed results from each company. Practically, the DCI size of joint-DCI can NOT be too small. It would be more reasonable to only consider the gain of a moderate DCI size or large DCI size, e.g., 84bits, 96bits and 108bits.  Regarding PDSCH throughput, different companies use different assumptions. Some assume that we can use a smaller CORESET to scheduling PDSCH, some assume that all the unused REs in the CORESET can be reused by PDSCH, etc. If a smaller CORESET is used, it should be clear that the gain of PDCCH blocking rate is gone in this case. On the other hand, currently, the rate-matching is performed in the granularity of CORESET, it is not clear how network can reuse all the unused REs in CORESET for PDSCH throughput. We would propose to make some detailed observations on the PDSCH throughput gain taking the detailed assumptions into account.  Overall, different companies use different simulation assumptions, even different simulation methodologies, we propose to make some detailed observations taking these different assumptions and methodologies into account. |
| Samsung | The maximum throughput gain, for the best-case scenario, is about 1%. That gain will not be realized in practice because:   1. It is not always possible to use CCEs of a CORESET for PDSCH. 2. Scheduling on two cells will not happen in every slot. When scheduling is on one cell, any gains need to be scaled down by the proportion of time scheduling is on two cells. The mechanism may actually result to throughput loss (either because single-cell scheduling and dual-cell scheduling use same DCI or because single-cell DCI uses padding to keep the “3+1” DCI sizes). 3. Regardless of whether or not the scheme is extended to the UL (not in scope), a UE need not be configured/support both DL CA and UL CA. In case of single UL cell, gains from scheduling on two cells need to be further scaled down and may be negative. 4. Blocking is not an issue, especially because the number of UEs with DL CA scheduled per slot on a 5/10 MHz carrier is small (e.g. it is typically 1 UE and rarely 2 UEs). 5. There is no impact on UE power consumption. |
| Huawei | Support to capture CCE saving ratio as intermediate LLS results. It is important to understand how some gains are presented while the gain is different when considering real scheduling as Qualcomm/ZTE mentioned, thus a common understanding of ‘optimistic gain’ would be useful for future discussion.  For PDCCH blocking rate and/or DL throughput, support to capture necessary clarification as many companies mentioned, for all presented simulation results, e.g.   * For PDCCH blocking   + One source result showing marginal gain uses UE geometry very different from many others.   + One source results showing marginal gain assumes “a roughly 2x CCE AL for DCI format X” and “probability distribution to CCE ALs of [1 2 4 8 16] of [20 20 20 20 0]% for DCI format 1\_1 and [0 20 20 20 20]% for DCI format X”, which is not acquired from LLS/SLS (while should be). * For PDSCH throughput   + One source result showing marginal gain assumes that “scheduling information of SCell reuses that of PCell”, although there is much room for the DCI of joint scheduling not to share scheduling information like MCS, FDRA.   + One source result showing no gain is analysis-based without SLS simulation   We disagree with the statement that “If a smaller CORESET is used, it should be clear that the gain of PDCCH blocking rate is gone in this case” since the system gain naturally comes from (1) using a smaller CORESET that is enjoying the single-DCI joint-scheduling PDCCH with similar PDCCH blocking rate, or (2) same CORESET configuration but with reduced PDCCH blocking rate. The network shall not be mandated to use large CORESET if there is PDCCH resource saving achieved already.  We have also clarified in our results that even with CORESET level rate matching, almost the same throughput gain can be achieved. This can also be captured.  Regarding SS comments above:   1. Explained in our contribution 2. Not necessarily true. Scheduling can/will usually be FDMed and the targeting scenario is with PDCCH capacity concern. Note our simulation is based on slot based scheduling while the potential gain can be increased if with span based CORESET (i.e. more CORESETs within a slot). 3. The gain will be increased if UL CA also supports joint scheduling using single DCI. The gain can be further increased if more carriers are supported with joint scheduling. 4. Similar to b). Again, the motivation of DSS is to ensure sufficient PDCCH capacity. There will be no need to do any enhancement since LTE to NR including specifying SCell scheduling PCell, if a network always has only one CA user. |
| OPPO | Considering performance from CCE saving ratio and PDCCH blockage reduction, One-to-two scheduling should be supported. |
| MediaTek | In our SLS simulation, CCE saving rate is used to derive the applied CORESET size for enhanced scheme based on legacy CORESET size, assuming the RU rate for DL control region is the same across legacy and enhanced schemes.   * For full-buffer traffic, the main UE throughput gain comes from overhead reduction. * For FTP traffic, the main UE throughput gain comes from RU reduction for PDSCH, assuming the same traffic arrival rate, e.g. RU reduction from ~46% to ~40% for 2GHz carrier frequency and from ~53% to ~37% for 700MHz carrier frequency. * This is why we observe higher UE throughput gain in FTP traffic than in full-buffer traffic, especially for cell-edge UEs. Because cell-edge UEs are more sensitive to RU rate due to inter-cell interference. * We also observe in the SLS results that a UE is not always scheduled with PDSCHs over 2 cells (30% of slots for full buffer traffic; 70% of slots for FTP traffic).   We’re supportive to this feature because we still see certain benefits for 2-cell CA case.  We also understand that it can provide more system benefits if current scope can be extended to cover CA with more than 2 cells and DCI for PUSCH so forward compatibility needs to be considered for detailed design if we decide to go for this feature in Rel-17 DSS. |
| vivo | *Some observations in our paper were omitted, I added the omitted part in 2.2.5.*  CCE saving alone is not a reasonable metric for concluding whether joint scheduling is beneficial.  Joint scheduling is considered truly beneficial only when the savings in CCE resources and reductions in blocking rates can bring an increase in overall throughput. Therefore, we suggest to focus on the evaluation of throughput gains. |
| Ericsson | On “CCE savings” we do not support capturing observations using such intermediate metric as it does not provide useful information without proper context. For example, a saving from 2 CCEs to 1 CCE would show as 100% reduction in “CCE savings” when overall impact would be <<1%.  On observations related to PDSCH throughput, it is not clear from the proposed observations what is gain shown by each proponent for agreed Combination 1 and agreed Combination 2.  Also, considering some of the proposed observations more specifically   * “MediaTek: For 96bits DCI, 16.7%/32.7% mean/cell-edge UE throughput gain for 2GHz….”   + Considering R1-2100611, this seems to be for the case of FTP traffic where 3symbol CORESET is assumed for 20MHz channel BW (in Table 2).   + Table 1 in R1-2100611 shows Avg. CCE = 7.08 for FTP traffic (legacy scheme) and Avg. CCE = 4.36 for FTP traffic (1stage DCI 96 bits) for 3 symbol coreset. Then 3sym CORESET at 15kHz SCS and 20MHz channel BW results in 48 available CCEs, with such large available CCEs, PDCCH blocking issues are not expected, then it is unclear how a CCE reduction from 7CCEs to 4CCEs provides a overall throughput gain of 16% or 32%. We request MTK to please clarify this.   + Also, the 3 symbol coreset for 20MHz channel BW is not aligned with any of the agreed combinations. * “Vivo: 2.32~3.12% throughput gain for 96bits DCI or 108bits DCI.”   + Considering R1-2100474, observation 5 says <=2.44% throughput gain for combination 1 and <=2.32% throughput gain for combination 2. The proposed observation should be modified to reflect that these are upper limits.   + Further, according to R1-2100474 - “…*We performed SLS based on this scheduling restriction (i.e., the determined RBG size) and the overhead reduction gain (i.e., the required CORESET BW in the above Tables)….”.* We request vivo to clarify if observation 5 is based on overhead reduction being available in every slot or only in some slots?     - As discussed in our (and other) contributions there are many slots where only 1CC is scheduled and for such slots there is no gain with single DCI.   Overall, as discussed in our contribution we expect single DCI scheduling PDSCH on two cells to provide marginal or no performance gain. |
| Moderator | (1) Regarding the observations on CCE saving, many companies provide simulation results on CCE saving. Although CCE saving leads to reduced PDCCH blocking probability, I think it is no harm to discuss or even capture the related observations.  (2) Regarding the detailed performance gain in term of PDCCH blocking probability, most companies show the curves and do not provide the concrete value in reduced PDCCH blocking probability. We can discuss further whether to use a template for collecting companies’ results.  (3) Regarding the PDSCH throughput, I think the current simulation results are quite diverse. We can further discuss the simulation assumptions for SLS, e.g., how to evaluate the impact on PDSCH throughput gain by configuring a smaller CORESET or reusing the available CCEs for PDSCH transmission, how to evaluate the impact on PDSCH throughput loss when the scheduling PDCCHs are dropped due to PDCCH blocking.  (4) Regarding the simulation results which I captured in the above observations, please companies check them and make update if needed. |
| Nokia, NSB | We see the core benefit of the feature in intra-band or inter-band CA with the same SCS, where multi-cell DCI can mimic a wider channel bandwidth. The benefits in DSS configuration might alone justify the additional feature.  On Samsung’s results, is it a correct understanding that the aggregation level (CCE consumption) is always 2x for the new larger DCI than the reference DCI? “**Figure 3** presents the blocking probability assuming a roughly 2x CCE AL for DCI format X and probability distribution to CCE ALs of [1 2 4 8 16] of [20 20 20 20 0]% for DCI format 1\_1 and [0 20 20 20 20]% for DCI format X” If this is true, that would explain the increase in blocking probability, but seems to be contrary to the CCE consumption evaluation earlier in the document.  We think capturing blocking probability improvement is a relevant metric, and perhaps a template for this can be used, but here it should be clear that blocking probability based on realistic AL distribution rather than a completely hypothetical one should be used. |
| MediaTek | On Ericsson’s question:  In Table 2 of R1-2100611, there are two tables for 2GHz.   * 1st table assumes 2-symbol CORESET * 2nd table assumes 3-symbol CORESET   The UE throughput gain Ericsson refers to is from the 2nd table. However, in the 1st table, the average/cell-edge UE throughput gain is 8.2/22.4% for FTP 3 traffic with packet size of 20Kbytes & 10 packets/s per UE. |

## Proposals for 1st GTW session

FL Proposal#1:

* Take above observations as conclusions

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

|  |  |
| --- | --- |
| **Company** | **View** |
| Intel | Agree with moderator’s proposal |
| Qualcomm | Discussions on the observations are necessary |
| CATT | Majority companies observe there are significant benefits from multi-cell scheduling via single DCI from several aspects. The above observations are long text, which is not friendly for reading. Maybe we can try the following wording:  *Multi-cell scheduling via single DCI is beneficial at least for reducing CCE consumption, reducing PDCCH blocking possibility, increasing PDSCH throughput, reducing PDCCH blind detection and power consumption.* |
| Samsung | Need to discuss the various issues and draw conclusive observations. |
| Huawei | Support the approach to capture observations with necessary clarification. FL observations canbe starting point. |
| OPPO | Agree with moderator’s proposal |
| MediaTek | Support to capture concise observations based on the submitted simulation results as a starting point. |
| vivo | Please see our comments in 2.2.5. We are not sure if we need to capture all above observations in the chairman note. We suggest to draw some conclusive observations. |
| Lenovo, Motorola Mobility | Generally Ok with the conclusive observation. |
| Ericsson | More discussion and updates are needed for the proposed observations |
| DOCOMO | Support |
| LG | Same view with other companies.  Need discussions on the possible conclusive observations. |
| Nokia, NSB | In general agree with the Feature Lead proposal. We should aim at deriving observations and conclusions for RAN#91 to take the final decision on whether to proceed with the design based on RAN1 findings rather than just ending up counting companies. |

## Proposals for 2nd round of discussion

FL Proposal#1:

* Further discuss the below observations:

On CCE saving by using a single DCI to schedule multiple PDSCHs on multiple carriers, simulation results are summarized below:

* 8 companies [OPPO, Huawei, HiSilicon, Intel, InterDigital, vivo, MediaTek, CATT] observe reduced CCE consumptions via simulation.
  + OPPO: CCE saving ratio is more than 10% for any DCI size even CA ratio is not large.
  + Huawei, HiSilicon: for DCI size in range of 108~72 bits,
    - 27.74%~42.95% average CCE saving ratio for Combination 1
    - 23.53%~45.02% average CCE saving ratio for Combination 2
    - 21.53%~41.89% average CCE saving ratio for Combination 3
    - 21.3%~43.29% average CCE saving ratio for Combination 4
  + Intel: The ratio of CCE saving is about 20~40%.
  + Vivo: joint-DCI scheduling brings more than
    - 33.09% CCE saving for combination 1,
    - 28.13% CCE saving for combination 2,
    - 32.59% CCE saving for combination 3,
    - 18.14% CCE saving for combination 4,
  + MediaTek: for Combination 1, saving rate is 21.3% for 84 bits DCI, 20.6% for 96 bits DCI.
  + CATT: for a DSS-DCI with payload size 60 bits – 108 bits,
    - 28% - 45% average CCE saving ratio for combination 1
    - 22.5%- 45% average CCE saving ratio for combination 2
    - 26.4% - 41.7% average CCE saving ratio for combination 3
    - 21.1% - 42.1% average CCE saving ratio for combination 4

On PDCCH blocking probability using a single DCI to schedule multiple PDSCHs on multiple carriers, simulation results are summarized below:

* 12 companies [OPPO, Huawei, HiSilicon, Intel, InterDigital, CATT, vivo, Nokia, NSB, Lenovo, Motorola Mobility, Qualcomm] observe decreased PDCCH blocking probability via simulation.
* 2 companies [ZTE, Ericsson] observed marginal performance gain in PDCCH blocking.
* 1 company [Samsung] observe higher PDCCH blocking compared to two DCIs scheduling two PDSCHs.

On PDSCH throughput, simulation results are summarized below:

* 4 companies [Huawei, HiSilicon, vivo, MediaTek] observe non-negligible PDSCH throughput gain via simulation.
  + Huawei, HiSilicon: 8~10% throughput gain for 108bits DCI or 96bits DCI.
  + Vivo: 2.32~3.12% throughput gain for 96bits DCI or 108bits DCI for combination 1/2/3, 1.42% throughput gain for combination4, but if the number of UE increases to 15 or 20, using single DCI to schedule multiple PDSCH may bring 0.2%~0.31% throughput loss for combination4 as the loss caused by increased scheduling granularity cannot be compensated by throughput gain brought by the saved PDCCH resources.
  + MediaTek: For 96bits DCI, 16.7%/32.7% mean/cell-edge UE throughput gain for 2GHz and 29~34%/63~100% mean/cell-edge UE throughput gain for 700MHz. In the 1st table, the average/cell-edge UE throughput gain is 8.2/22.4% for FTP 3 traffic with packet size of 20Kbytes & 10 packets/s per UE.
    - There are two tables for 2GHz: 1st table assumes 2-symbol CORESET and 2nd table assumes 3-symbol CORESET. The UE throughput gain Ericsson refers to is from the 2nd table.
* 1 company [Samsung] observe marginal throughput gain 1.07% for Combination 1 and 0.084% for Combination 2 for 108bits DCI via estimation.
* 1 company [ZTE] observe 13.4 or 8.7% loss for inter-band case and intra-band case for 84 bits DCI via simulation.

On UE blind detection reduction and power saving, companies’ simulation results and views are summarized below:

* 6 companies [Huawei, HiSilicon, Lenovo, Motorola Mobility, Nokia, NSB] observe UE power saving by using a single DCI to schedule multiple PDSCHs on multiple carriers.
  + Huawei, HiSilicon: save up to 6.67%~15% power consumption.

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

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

FL Proposal#2:

* Take below simulation assumptions to further evaluate the impact on PDSCH throughput due to multiple carriers scheduled by a single DCI
* Companies are encouraged to report the simulation assumptions on how to use the saved CCEs for PDSCH transmission.

Table 2: System level simulation assumptions

|  |  |
| --- | --- |
| **Parameters** | **Values** |
| Performance metrics | Average UE throughput, 5%-tile UE throughput |
| Link adaptation | Separate MCS and time-frequency resources for each scheduled carrier |
| Deployment scenario | Inter-band: 700MHz + 2GHz  Intra-band: 2GHz + 2GHz |
| CORESET configuration | Follow agreed link level simulation assumptions.  Companies report the carrier where the CORESET is configured. |
| Percentage of UEs with CA capability per cell | 100% |

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

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

# 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:

|  |  |
| --- | --- |
| Company | Key Proposals/Observations |
| ZTE | Observation 5: 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 6: 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 7: 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 8: If single DCI scheduling two PDSCHs on two carriers is supported, RAN1 needs to further study how to indicate the two scheduled carriers.  Observation 9: If single DCI scheduling two PDSCHs on two carriers is supported, RAN1 needs to further study how to guarantee the current BD/CCE budget. |
| Huawei, HiSilicon | Observation 7: For the DCI scheduling multi-carrier scheduling, some DCI fields can be predefined to be independent for separate PDSCHs, some fields can be predefined to be common for 2 PDSCHs, and the other fields can be configurable to be independent or common based on network decisions.  Observation 8: Even with the simplest DCI design of sharing some fields according to network configuration, significant bits can be saved, e.g. to 84 bits for the presented evaluation combinations and corresponding gains. The flexibility is still under network control.  Observation 9: Scheduling PDSCH(s) on multiple cells with a single PDCCH can be specified without impact on the current PDCCH blind decoding budget. |
| CATT | Proposal 3: The DCI content for multi-cell PDSCH scheduling and HARQ feedback procedure need to be further studied. |
| vivo | Proposal 2. Field type (i.e., shared or cell-specific) of each information field in joint-DCI needs to be investigated.  Observation 7. 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 |
| Intel | Observation 3: Potential specification impacts include but not limited to   * The RRC configuration * Separate design for each DCI field * UE complexity on PDCCH detection. * HARQ-ACK transmission. |
| Nokia, NSB | Observation 3: The baseline design would be to determine DCI format fields based on primary of the two-cells and interpret the fields for the secondary of the two-cells as in case of BWP switching R15. Some fields could be further optimized or doubled in the DCI format which is FFS. |
| Lenovo, Motorola Mobility | Proposal 2: Further study payload size reduction for the two-cell scheduling DCI.  Proposal 3: The two-cell scheduling DCI can schedule one PDSCH on one cell or two PDSCHs on two cells. |
| LG | Proposal #2: At least following issues would need to be addressed, and relevant specification impacts (and standardization workload for them) are expected, if the single DCI based multi-cell PDSCH scheduling is introduced.   * How to indicate the multiple cells with PDSCH transmission by single scheduling DCI * How to compose (and signal) the DCI fields in the multi-cell PDSCH scheduling DCI * How to construct PDCCH search space for the multi-cell scheduling DCI transmission * How to allocate (and handle) PDCCH BD candidates for the multi-cell scheduling DCI |
| ETRI | Observation 1: Multi-cell scheduling via a single DCI should be generally applicable for any valid CA scenario.  Observation 2: Multi-cell scheduling via a single DCI should allow a sufficiently wide range of scheduling flexibility to support different scenarios.  Observation 3: For multi-cell joint scheduling, the principle that one PDSCH is allocated within a cell needs to be kept the same to minimize the specification workload.  Observation 5: Need of dynamic switching between single-cell DCI and multi-cell DCI can be discussed together with the design of the multi-cell DCI contents. |
| ASUSTeK | Proposal 2-1: At least DCI fields about the feedback information of the multiple PDSCHs can be shared between the multiple PDSCHs, e.g. TPC command for scheduled PUCCH, PUCCH resource indicator, PDSCH-to-HARQ feedback timing indicator, downlink assignment index  Proposal 2-2: At least DCI fields about the resource assignment or the transmission parameter of the respective PDSCHs cannot be shared between the multiple PDSCHs, e.g. TDRA field, FDRA field, TB information, HARQ process number, TCI field.  Proposal 3: Constrain one of the two scheduled cell to be the scheduling cell to reduce the number of bits that are induced to the DCI formats for supporting the multi-cell PDSCH scheduling via a single DCI. |
| Intel | Observation 1: To support 2-cell scheduling by a single DCI, at least the following bit fields are likely to be duplicated: FDRA, MCS/NDI/RV and Antenna ports/TCI. TDRA field may be duplicated too. |
| InterDigital | Support a single DCI to schedule two PDSCH in different cells. |
| 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:   * In the assumed scenario (e.g. Inter-band CA with PCell (DSS carrier) and an SCell), CRC field attached to DCI (i.e. 24-bit) can be shared between the scheduled multiple cells.   Observation 3:   * In the assumed scenario (e.g. Inter-band CA with PCell (DSS carrier) and an SCell), 3-bit CIF may be reasonable assumption for single DCI scheduling PDSCH on multiple cells.   Observation 4:   * In the assumed scenario (e.g. Inter-band CA with PCell (DSS carrier) and an SCell), at least the case where the number of PDSCH TBs on multiple cells scheduled by single DCI is two can be considered.   Observation 5:   * In the assumed scenario (e.g. Inter-band CA with PCell (DSS carrier) and an SCell), it may be better to separate Time domain resource assignment field for each scheduled cell.   Observation 6:   * In the assumed scenario (e.g. Inter-band CA with PCell (DSS carrier) and an SCell), it may be better to separate Frequency domain resource assignment field for each scheduled cell.   Observation 7:   * Whether/how to support some indications in DCI for multiple scheduled cells can be considered.   + e.g. rate matching indicator, BWP indicator, CSI request and SRS request   Observation 8:   * How to determine the size of DCI scheduling PDSCH on multiple cells can be considered.   Observation 9:   * 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 10:   * 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:**

|  |  |
| --- | --- |
| **Company** | **Key Proposals/Observations** |
| ZTE | Observation 10: 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 | The HARQ-ACK feedback procedure may also need to be further studied accordingly, e.g. the SCS and scheduling/feedback timing may be different for the different scheduled cells. We also provide some tentative insights below from our side:   * For type1 HARQ-ACK codebook, current mechanism can be directly reused if two separate PDSCHs are scheduled on different cells respectively. * Design of C-DAI and T-DAI in one DCI for counting multiple PDSCHs scheduled by one DCI should be considered. * HARQ-ACK timing needs to be further considered as the scheduling timing and feedback timing may be both different on the two scheduled cells. |
| Intel | Observation 3: Potential specification impacts include but not limited to   * The RRC configuration * Separate design for each DCI field * UE complexity on PDCCH detection. * HARQ-ACK transmission. |
| ZTE | Observation 8: If single DCI scheduling two PDSCHs on two carriers is supported, RAN1 needs to further study how to perform the corresponding HARQ-ACK feedback. |
| Lenovo, Motorola Mobility | Observation 7: HARQ-ACK feedback for the two PDSCHs scheduled by a single DCI is included in same HARQ-ACK codebook.  Proposal 4: Further study Type-2 HARQ-ACK codebook determination. |
| Samsung | More important for now is to identify bit savings from fields that have no impact on scheduling (e.g. C-RNTI, TPC, …) and determine the total number of bits.  If companies want to re-use FDRA/MCS/… on two cells, additional requirements are then needed such as evaluation of throughout loss through system simulations, description of solutions for operation with different SCS on different cells, … |

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.

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

## Proposals for 1st GTW session

FL Proposal#2:

For the two-cell scheduling DCI, if supported, study below options for payload reduction:

* All the fields of the DCI can be divided into three types:
  + First type field: common to the two PDSCHs
  + Second type field: separate to the two PDSCHs
  + Third type field: common or separate to the two PDSCHs dependent on RRC configuration
* Other solutions are not precluded, e.g., using 2-stage DCI to schedule two PDSCHs on two carriers.

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

|  |  |
| --- | --- |
| **Company** | **View** |
| Intel | Not sure if 2-stage DCI is in the scope. If not, prefer to not list it as example to minimize potential standardization efforts. |
| CATT | From our understanding, this proposal makes sense only if the two-cell scheduling DCI is supported. We don’t need ‘if supported’ in the main bullet. |
| Samsung | Need to first conclude whether or not 2-cell scheduling DCI is supported - no point for any other discussion. |
| Huawei | OK with FL proposal |
| OPPO | Agree with moderator’s proposal |
| MediaTek | Agree with moderator’s proposal. |
| Lenovo, Motorola Mobility | Agree with moderator’s proposal. |
| LG | Same view with Samsung.  Whether or not to support 2-cell scheduling by single DCI should be concluded first as per WID before proceeding discussions on any details. |
| Nokia, NSB | Probably no time to address these issues in the 1st GTW session, but would be good to have some outline of what the design principles are as an output of this meeting. Tend to think 2-stage DCI is not in scope. |

# Miscellaneous (Low priority)

Regarding some low priority issues, companies’ views are summarized as below:

|  |  |
| --- | --- |
| Company | Key Proposals/Observations |
| Huawei, HiSilicon | Observation 12: Using single DCI scheduling multi-carriers has large potential to be deployed with the deployment scenario with 3 carriers and UL scheduling. |
| CATT | Proposal 2: Two TBs should be scheduled separately on different serving cells for multi-cell PDSCH scheduling via a single DCI. |
| vivo | Proposal 3. Clarify whether PUSCH multi-cell scheduling should be studied. |
| ZTE | Proposal 2: If TU permits, RAN1 considers one DCI scheduling two PDSCHs on the same carrier instead of one DCI scheduling two PDSCHs on two carriers. |
| MediaTek | Proposal 2: Continue to work on detailed design of multi-cell PDSCH scheduling via single DCI with the following design considerations.   * PDCCH blind decoding complexity is not worse than Rel-16 * Scalable DCI size based on the number of scheduled cells * Switch of same/different TDRA/FDRA across the scheduled cells * Forward compatibility to CA with more than 2 cells |
| ETRI | Observation 4: For multi-cell joint scheduling, scheduling more than two cells using a single DCI can be considered. |
| Nokia, Nokia Shanghai Bell | Proposal 1: Support multi-cell DCI in R17, focus on multiple SCell (2 or more) with the same/similar carrier size and SCS first. Strive to keep DCI format 1\_1 payload <106bits (including CRC). |

FL suggestions:

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

* Using two-stage DCI for scheduling multiple PDSCHs on multiple carriers
* Using a single DCI for scheduling multiple PUSCHs on multiple carriers
* Using a single DCI for scheduling multiple PDSCHs on same carrier
* Using a single DCI for scheduling more than 2 carriers

# References

1. [R1-2100111](file:///D:\RAN1\RAN1%23104-e\tdocs\R1-2100111.zip) Discussion on Multi-cell PDSCH Scheduling via a Single DCI ZTE
2. [R1-2100187](file:///D:\RAN1\RAN1%23104-e\tdocs\R1-2100187.zip) Discussion on multi-cell PDSCH scheduling via a single DCI OPPO
3. [R1-2100194](file:///D:\RAN1\RAN1%23104-e\tdocs\R1-2100194.zip) Discussion on multi-carrier scheduling using single PDCCH Huawei, HiSilicon
4. [R1-2100359](file:///D:\RAN1\RAN1%23104-e\tdocs\R1-2100359.zip) Discussion on multi-cell PDSCH scheduling via a single DCI CATT
5. [R1-2100474](file:///D:\RAN1\RAN1%23104-e\tdocs\R1-2100474.zip) Discussion on joint scheduling vivo
6. [R1-2100611](file:///D:\RAN1\RAN1%23104-e\tdocs\R1-2100611.zip) On Multi-cell PDSCH Scheduling via Single DCI MediaTek Inc.
7. [R1-2100678](file:///D:\RAN1\RAN1%23104-e\tdocs\R1-2100678.zip) On 2-cell scheduling via single DCI Intel Corporation
8. [R1-2100720](file:///D:\RAN1\RAN1%23104-e\tdocs\R1-2100720.zip) On support of Single DCI scheduling two cells Nokia, Nokia Shanghai Bell
9. [R1-2100771](file:///D:\RAN1\RAN1%23104-e\tdocs\R1-2100771.zip) Discussion on multi-cell PDSCH scheduling via a single DCI Lenovo, Motorola Mobility
10. [R1-2100886](file:///D:\RAN1\RAN1%23104-e\tdocs\R1-2100886.zip) Discussion on multi-cell PDSCH scheduling via a single DCI LG Electronics
11. [R1-2101089](file:///D:\RAN1\RAN1%23104-e\tdocs\R1-2101089.zip) Discussion on multi-cell PDSCH scheduling via a single DCI ETRI
12. [R1-2101238](file:///D:\RAN1\RAN1%23104-e\tdocs\R1-2101238.zip) Considerations for scheduling on two cells using a single DCI format Samsung
13. [R1-2101293](file:///D:\RAN1\RAN1%23104-e\tdocs\R1-2101293.zip) On the support of single DCI scheduling multi-cell InterDigital, Inc.
14. [R1-2101363](file:///D:\RAN1\RAN1%23104-e\tdocs\R1-2101363.zip) Views on Rel-17 DSS Multi-cell PDSCH scheduling via a single DCI Apple
15. [R1-2101491](file:///D:\RAN1\RAN1%23104-e\tdocs\R1-2101491.zip) Multi-cell PDSCH scheduling via a single DCI Qualcomm Incorporated
16. [R1-2101562](file:///D:\RAN1\RAN1%23104-e\tdocs\R1-2101562.zip) Study on single DCI scheduling PDSCH on multiple cells Ericsson
17. [R1-2101633](file:///D:\RAN1\RAN1%23104-e\tdocs\R1-2101633.zip) Discussion on multi-cell PDSCH scheduling via a single DCI for NR DSS NTT DOCOMO, INC.
18. [R1-2101657](file:///D:\RAN1\RAN1%23104-e\tdocs\R1-2101657.zip) Discussion on multi-cell PDSCH scheduling via a single DCI ASUSTeK
19. R1-2101789 Discussion on Multi-cell PDSCH Scheduling via a Single DCI ZTE

# List of agreements:

## 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