**3GPP TSG RAN WG1 Meeting #103-e R1-20XXXXX**

**e-Meeting, October 26th – November 13th, 2020**

**Source: Moderator (Lenovo)**

**Title: Feature lead summary#1 on multi-cell scheduling by 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 RAN1 #102-e meeting, the following agreements under the “Multi-cell PDSCH scheduling via a single DCI” agenda item of was reached:

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| 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 |

In Section 2, candidate schemes for multi-cell PDSCH scheduling, evaluation assumptions as well as 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. Several open questions are listed in this section and companies are encouraged to provide their inputs for each open question.

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

# Summary of contributions

The section summarises key proposals and observations from submitted contributions. A few proposals and questions to resolve based on the general leaning of the companies are captured below.

## Candidate schemes for multi-cell PDSCH scheduling

Regarding number of TBs carried by the multiple PDSCHs scheduled by a single DCI, many companies show their views in below contributions. Based on the summary, most companies think the scheduled multiple PDSCHs carrying a single TB will lead to significant standard impact on CA framework, HARQ and protocol layer design and propose the scheduled multiple PDSCHs carry different TBs.

For two PDSCHs on two carriers scheduled by a single DCI, companies’ views on same or different TBs are summarized below:

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| Company | Key Proposals/Observations |
| Huawei, HiSilicon | *Scheme 1: one DCI schedules two PDSCHs over two cells*  *Scheme 2: one DCI schedules one PDSCH over two cells* |
| vivo | *Proposal 2. The study focuses on the case that the two PDSCH jointly scheduled by a single DCI correspond to different TBs.* |
| CATT | *Proposal 2: Two TBs should be scheduled separately on different serving cells for multi-cell PDSCH scheduling via a single DCI.* |
| Spreadtrum | *Clarify which the scheme is in the scope.* |
| ETRI | *Observation 4: For multi-cell joint scheduling, the principle that one PDSCH does not span multiple cells can be kept to minimize the workload.* |
| Lenovo, Motorola Mobility | *Observation 5: Scheduling a single TB on two carriers is not in the scope of Rel-17 DSS.* |
| NTT DOCOMO | *Observation 11:*   * *Whether the same TB and/or different TBs is/are scheduled on multiple cells can be considered.* |

Based on the majority companies’ views, below proposal can be discussed:

FL proposal#1:

For Rel-17 DSS, when multiple PDSCHs are scheduled by a single DCI, the multiple PDSCHs carry different TBs.

## Evaluation

### Evaluation assumptions:

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| **Parameters** | **Values** |
| Scenario | Inter-band CA  Intra-band CA |
| Bandwidth | PCell: 10/20MHz  SCell: 10/20/100MHz |
| Simulation cases | Case 1: two DCIs with baseline payload size schedule two PDSCHs on two carriers, respectively  Case 2: a single DCI with larger payload size schedules two PDSCHs on two carriers |
| DCI payload size (excluding CRC) | Single PDSCH scheduling: 60 bits  Multi-cell PDSCH scheduling: 72/84/96/108/120 bits |
| Evaluation metrics | PDCCH blocking probability, CCE saving ratio, PDSCH throughput improvement, UE power saving |

### 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 think the PDCCH blocking probability can be alleviated.

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:

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| Company | Key Proposals/Observations |
| Huawei, HiSilicon | *Observation 1: For 700MHz + 800MHz scenario, one PDCCH scheduling PDSCH(s) on two cells can achieve up to 23%~50% average CCE saving ratio.*  *Observation 2: For 800MHz + 1800MHz scenario, one PDCCH scheduling PDSCH(s) on two cells can achieve up to 18.2%~50.4% average CCE saving ratio.*  *Observation 3: For 1800MHz + 3500MHz scenario, one PDCCH scheduling PDSCH(s) on two cells can achieve up to 12.8%~43% average CCE saving ratio.*  *Observation 4: Single DCI scheduling PDSCH(s) on two cells can reduce the PDCCH blocking probability obviously* |
| Vivo | *Observation 1. Compared with using single DCI, a joint DCI scheduling two PDSCHs on two cells brings around 44.87% and 44.51% CCE saving gain if the joint DCI size (excluding CRC) is less than 60% of the total size of two single DCI at 2.6GHz and 4GHz respectively, and the gain becomes less significant if the compression rate of joint DCI size increases.*  *Observation 3. Compared with using single DCI, a joint DCI scheduling two PDSCHs on two cells brings around 13.95% or 13.57% reduction in PDCCH blocking rate if the joint DCI size (excluding CRC) is less than 60% of the total size of two single DCI at 2.6GHz and 4GHz respectively, and the reduction rate becomes less significant if the compression rate of joint DCI size increases.*  *Observation 4. PDCCH blocking rate reduction by joint DCI scheduling can only bring a marginal <=3.31% throughput gain in practical scenarios at 4GHz.* |
| CATT | *Multi-cell scheduling via a single DCI can significantly reduce the possibility of PDCCH blocking. Consequently, the PDCCH capacity increase remarkably.*  *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.* |
| OPPO | *Observation 2: The smaller DCI size increases, the more UEs achieve gain from one-to-two scheduling.* |
| MediaTek | *Observation 2: Around 30% DCI overhead reduction is observed for Rel-17 DCI aggregation for x-carrier scheduling, assuming that the aggregated DCI size is scaled with the number of scheduled cells.* |
| Lenovo, Motorola Mobility | *Observation 1: 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 2: 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.* |
| 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 4: *Coverage and relative BLER comparisons for DCI format C2 further worsen for operation under less favorable conditions such as with some correlation or blockage of UE receiver antennas or for 2 UE receiver antennas.*  Observation 5: *For DSS, a maximum gain in resources per slot from scheduling PDSCH on 2 cells using a single DCI format is ~0.35% for a BWP of 20 MHz and ~0.07% for a BWP of 100 MHz on the scheduling cell.* |
| Nokia, NSB | *Observation 1: Two-cell DCI format reduces overhead by at least 24 CRC bits, and if single DCI field applies to both cells (at least for HARQ-related parameters), further significant PDCCH overhead reduction is expected.*  *Observation 6:*   1. *A 120 bits (>106bits) PDCCH payload does not fit anymore to 1CCE, this means that for 50-70% users, aggregation level must be doubled. For the AL>2, the 120bit PDCCH payload probability is not anymore significantly increased compared to 80 and 100bit, and could be also compensated by increasing PDCCH TX power.* 2. *When comparing 80bit and 100bits PDCCH payload, the AL probability is similar* |
| InterDigital | *Observation 2:**PDCCH blocking probability and CCE utilization can be reduced by using a single DCI scheduling PDSCH on two cells.* |
| DOCOMO | *Observation 1:*   * *PDCCH of P(S)Cell/SCell scheduling PDSCH on multiple cells using a single DCI can improve PDCCH resource efficiency.* |
| Ericsson | Initial evaluations indicate that DCI scheduling PDSCH on two cells (mc-DCI) provides no/marginal performance gains. |
| Qualcomm | *Observation 1: The 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.* |

### PDSCH throughput improvement

Based on Rel-15 NR CORESET design principle, the unused control resource REs can be scheduled for PDSCH transmission, thus some companies observed PDSCH throughput improvement due to the reduction of PDCCH overhead.

However, some companies observed PDSCH throughput loss due to the inappropriate scheduling parameters that have to be shared between the two carriers even though PDCCH blocking probability is decreased.

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

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| Company | Key Proposals/Observations |
| Huawei, HiSilicon | *Observation 5: For two carriers of 10MHz @ 700MHz&800MHz frequency with or without DSS, when the traffic load is high, one PDCCH scheduling PDSCH(s) on two carriers can achieve 7.2% to 15% throughput gain.* |
| Vivo | *Observation 2. CCE saving by joint DCI scheduling can bring up to around 6.41% throughput gain if the PDSCH can rate match around PDCCH.* |
| OPPO | *Observation 1: One-to-two scheduling has 13.5% throughput gain due to PDCCH overhead reduction.* |
| ZTE | *Observation 2:*  *For Case B (most of the DCI fields are separate indicated for two carriers), the cell throughput performance is almost the same as the baseline and the gain of PDCCH blocking rate is marginal.*  *For Case C (most of the DCI fields are shared between two carriers), the cell throughput performance is decreased by 13~16% compared with the baseline though the PDCCH blocking rate is decreased.* |
| Samsung | Observation 4: *Coverage and relative BLER comparisons for DCI format C2 further worsen for operation under less favorable conditions such as with some correlation or blockage of UE receiver antennas or for 2 UE receiver antennas.*  Observation 5: *For DSS, a maximum gain in resources per slot from scheduling PDSCH on 2 cells using a single DCI format is ~0.35% for a BWP of 20 MHz and ~0.07% for a BWP of 100 MHz on the scheduling cell.* |

### 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:

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| 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.* |
| MediaTek | *Observation 3: There is 50% and 15% reduction are observed for UE blind decoding complexity and power consumption, respectively.* |
| Charter Communications | *Observation 1: The ability to schedule PDSCH on multiple cells using a single DCI will help reduce UE power consumption when operating with ultra-wide carriers, for e.g., NR beyond 52.6 GHz.* |
| Lenovo, Motorola Mobility | *Observation 3: 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.* |

### Preliminary observations

Preliminary observations on PDCCH blocking probability using a single DCI to schedule multiple PDSCHs on multiple carriers are summarized below:

* 14 companies [Huawei, HiSilicon, vivo, CATT, OPPO, MediaTek, Lenovo, Motorola Mobility, Intel, Nokia, NSB, InterDigital, DOCOMO, Qualcomm] observed decreased PDCCH blocking probability or reduced CCE consumptions.
* 3 companies [ZTE, Samsung, Ericsson] observed marginal performance gain in PDCCH blocking.

Preliminary observations on PDSCH throughput improvement by scheduling unused control resource REs for PDSCH transmission are summarized below:

* 4 companies [Huawei, HiSilicon, vivo, OPPO] observed about 6~15% performance gain.
* 1 company [ZTE] observed 13~16% performance loss due to shared scheduling information for the two carriers.

Preliminary observations on UE blind decoding reduction and power saving are summarized below:

* 8 companies [Huawei, HiSilicon, MediaTek, Charter Communications, Lenovo, Motorola Mobility, Nokia, NSB] think multi-cell scheduling by a single DCI can save UE power.

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

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

**Company views:**

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| --- | --- |
| **Company** | **Key Proposals/Observations** |
| CATT | Proposal 1: Multi-cell PDSCH scheduling via a single DCI should be further studied considering it can bring significant benefits in terms of PDCCH capacity, PDSCH throughput and network flexibility. |
| Vivo | Observation 1. Compared with using single DCI, a joint DCI scheduling two PDSCHs on two cells brings around 44.87% and 44.51% CCE saving gain if the joint DCI size (excluding CRC) is less than 60% of the total size of two single DCI at 2.6GHz and 4GHz respectively, and the gain becomes less significant if the compression rate of joint DCI size increases. |
| Spreadtrum | Support multi-cell PDSCH scheduling via a single DCI. |
| 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. |
| ZTE | Proposal 1: RAN1 further discusses the necessity, gain, open issues and possibility of timely completion of single DCI scheduling two PDSCHs on two carriers. |
| Charter Communications | Proposal 1: Consider enhanced multi-carrier operation where a single DCI can schedule PDSCH on two non-DSS cells with the same SCS, including SCells with a dormant BWP, for energy-efficient and low-latency NR performance. |
| Lenovo, Motorola Mobility | Proposal 1: Support using a single DCI to schedule two PDSCHs on two carriers. |
| MediaTek | Proposal 4: Support DCI aggregation for cross-carrier scheduling in Rel-17 DSS.   * FFS whether DCI aggregation for cross-carrier scheduling is 1-stage or 2-stage |
| 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. Strive to keep DCI format 1\_1 payload <106bits (including CRC). |
| InterDigital | Proposal 1: Support a single DCI to schedule two PDSCH in different cells. |

So far, 10 companies [CATT, Spreadtrum, ASUSTeK, Charter Communications, MediaTek, Lenovo, Motorola Mobility, Nokia, NSB, InterDigital] clearly propose to support such multi-carrier scheduling. 2 companies [Samsung, Apple] suggests not to introduce this feature in Rel-17 DSS.

Based on majority companies’ views, below proposal is made:

FL Proposal#2:

* Support using a single DCI to schedule two PDSCHs on two carriers.

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 |
| 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: It is possible to reduce the DCI payload around 18% when using single DCI joint scheduling two carriers instead of two separate DCIs, still with significant performance improvement without losing network scheduling flexibility. |
| vivo | Proposal 4. For joint DCI with DCI payload compression, study the trade-off between system capacity improvement due to CCE saving/PDCCH blocking rate reduction and the spectrum efficiency loss due to degraded scheduling flexibility.  Proposal 5. The fields type (shared or cell-specific) in joint DCI needs to be investigated. |
| CATT | Proposal 3: The DCI content for multi-cell PDSCH scheduling and HARQ feedback procedure need to be further studied. |
| 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 |
| Spreadtrum: | 1. The DCI fields should be discussed and study whether or not the scheduling information should be same or different for the multiple PDSCHs. |
| Samsung | Observation 1: Consideration of a DCI format scheduling PDSCH receptions on two cells should avoid any throughput degradation over using two DCI formats and any new design requirements on the gNB scheduler.  Observation 2: For TDD operation and no scheduling restrictions, a DCI format scheduling 2 cells can avoid duplication for only the CRC bits.  Observation 3: DCI format size 1\_1 is preferable to DCI format C2 across the geometry CDF, particularly for UEs above the 30% point of the geometry CDF which are more likely to operate with CA.  Observation 4: Coverage and relative BLER comparisons for DCI format C2 further worsen for operation under less favorable conditions such as with some correlation or blockage of UE receiver antennas or for 2 UE receiver antennas.  Observation 5: For DSS, a maximum gain in resources per slot from scheduling PDSCH on 2 cells using a single DCI format is ~0.35% for a BWP of 20 MHz and ~0.07% for a BWP of 100 MHz on the scheduling cell.  Observation 6: The size matching of DCI format 0\_1 with DCI format 1\_1 that is required when using DCI format C2 reduces overhead savings from using DCI format C2.  Observation 7: Introduction of a DCI format scheduling PDSCH on two cells by parallelizing use of field for scheduling on a single cell does not provide any material benefit over a DCI format scheduling PDSCH on a single cell. |
| OPPO | Observation 2: The smaller DCI size increases, the more UEs achieve gain from one-to-two scheduling. |
| APPLE | Observation 2: Rel-16 Single-DCI Multi-TRP solutions significantly restrict PDSCH scheduling flexibility, and, is only designed for PDSCH repetition, i.e. single TB case |
| ASUSTeK | Proposal 2-1: DCI fields about reporting HARQ-ACK information are shared between the multiple PDSCHs scheduled by a single DCI.  Proposal 2-2: DCI fields about resource assignment and transmission parameters are separate between the multiple PDSCHs scheduled by a single DCI.  Proposal 3: Constrain one of the two cells scheduled by a single DCI to be the scheduling cell. |
| ZTE | Observation 3: If single DCI scheduling two PDSCHs on two carriers is supported, to guarantee at least the moderate flexibility, the minimum size of this enhanced DCI for one-to-two scheduling is 93bits compared with 60 bits for legacy scheduling.  Observation 4: 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 5: If single DCI scheduling two PDSCHs on two carriers is supported, RAN1 needs to further study whether to apply DCI format 1\_1/1\_2 or introduce a new DCI format for one-to-two scheduling.  Observation 6: If single DCI scheduling two PDSCHs on two carriers is supported, RAN1 needs to further study how to indicate the two scheduled carriers.  Observation 7: 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 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. |
| Charter Communications | Proposal 1: Consider enhanced multi-carrier operation where a single DCI can schedule PDSCH on two non-DSS cells with the same SCS, including SCells with a dormant BWP, for energy-efficient and low-latency NR performance. |
| Lenovo, Motorola Mobility | Observation 4: Only non-fallback DCI can be configured to schedule one PDSCH on one carrier or two PDSCHs on two carriers. |
| MediaTek | Proposal 3: Both 1-stage DCI aggregation and 2-stage DCI aggregation for cross-carrier scheduling should be included for the evaluation. |
| 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. |
| ETRI | Observation 1: Multi-cell scheduling via a single DCI should be generally applicable for both the DSS scenario and the non-DSS scenario.  Observation 2: Decision on support of the joint multi-cell scheduling should be made by considering both the DSS scenarios and general CA scenarios. If agreed to specify, the design should also target both the scenarios.  Observation 3: The multi-cell joint scheduling should allow a sufficiently wide range of scheduling flexibility to support different scenarios.  Observation 4: For multi-cell joint scheduling, the principle that one PDSCH does not span multiple cells can be kept to minimize the workload.  Observation 5: For multi-cell joint scheduling, scheduling more than two cells using a joint DCI can be considered. |
| 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.  Observation 4: In DSS a typical DCI size with CRC would be 76 bits for single cell DCI, while for double cell DCI could be around 110bits when allowing for fully flexible allocation of TDRA, FDRA, MCS, HARQ ID, RV, NDI and Antenna ports.  Observation 5: In FR2 CA a typical DCI format 1\_1 size with CRC would 80bits, while four-cell DCI format could be around 88bits, when allowing for NDI field and 1-bit scheduling indication per cell. |
| InterDigital | Support a single DCI to schedule two PDSCH in different cells. |
| DOCOMO | Observation 2:   * The required DCI size for the agreed scenarios should be discussed prior to performance gain discussion.   Observation 3:   * 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 6:   * 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 7:   * 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 8:   * 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 9:   * How to determine the size of DCI scheduling PDSCH on multiple cells can be considered. |
| Ericsson | Following design aspects for single DCI scheduling PDSCH on two cells should be considered in the study   1. When single DCI is used to schedule PDSCH on two cells, whether the two scheduled cells are allowed to have different configuration for at least the following attributes:    1. Numerology used on each scheduled cell    2. Channel BW (and BWP BW) of each scheduled cell    3. MIMO configuration of each scheduled cell    4. HARQ processes/TBs/MCSs of each scheduled cell    5. FDRA/TDRA (including type) used for each scheduled cell 2. When single DCI is used to schedule PDSCH on two cells, whether the corresponding DCI format always schedules PDSCH on both cells or whether it is also used to schedule single cell PDSCH. 3. When UE monitors the DCI format for single DCI scheduling PDSCH on two cells, whether the UE can be configured to also monitor existing DCI format(s) scheduling PDSCH on single cell (i.e. 1-0/1-1/1-2). 4. Handling DCI size budget and DCI size-matching when UE is configured to monitor the DCI format for single DCI scheduling PDSCH on two cells. 5. Whether the DCI format supports the functionality of all the DCI fields specified for existing DCI formats or whether it supports only a limited subset of DCI fields. 6. For each DCI field of the DCI format, whether the DCI field jointly indicates the functionality for both cells or whether separate DCI fields for each cell are used to indicate the respective functionality. |
| Qualcomm | Proposal 1: Consider further DCI compression schemes that are effective for the cases where the scheduled cells are highly correlated (e.g., intra-band CA).  Proposal 2: Following should be realized:   * The UE is able to know a set of PDCCH candidates for the DCI format scheduling PDSCHs for a given set of scheduled cells, based on the higher-layer configurations, before blind decodes * NW can schedule one cell or multiple cells by the DCI format for multi-cell PDSCH scheduling.   Proposal 3: The UE monitors a set of PDCCH candidates for a DCI format that can schedule PDSCH(s) on a set of cell(s). A field in the DCI format tells the UE on which cell(s) data is actually scheduled amongst the set of cells. |

Discussion points:

Q1: For two PDSCHs on two carriers scheduled by a single DCI, there may be two options:

* Option 1: One PDSCH is cross-carrier scheduled and another PDSCH is self-scheduled.
* Option 2: Both PDSCHs are cross-carrier scheduled;

E.g., in Option 1, the DCI transmitted on cell 1 schedules one PDSCH on cell 1 via self-scheduling and another PDSCH on cell 2 via cross-carrier scheduling; in Option 2, the DCI transmitted on cell 1 schedules one PDSCH on cell 2 via cross-carrier scheduling and another PDSCH on cell 3 via cross-carrier scheduling.

Shall we support at least Option 1 or both options?

Companies are encouraged to provide comments in the table below.

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| **Company** | **View** |
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Q2: Will a new DCI format be introduced, or an existing non-fallback DCI be reused to support multi-cell PDSCH scheduling by a single DCI?

Companies are encouraged to provide comments in the table below.

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

Q3: Whether the multi-cell scheduling DCI can be also used to schedule a single PDSCH on one carrier?

Companies are encouraged to provide comments in the table below.

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

Q4: When UE monitors the DCI format which can schedule two PDSCHs on two cells, can the UE be configured to also monitor existing DCI (i.e., 1-0/1-1/1-2) scheduling a single PDSCH on a single cell?

Companies are encouraged to provide comments in the table below.

|  |  |
| --- | --- |
| **Company** | **View** |
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Q5: When UE monitors the DCI format which can schedule two PDSCHs on two cells, whether the BD/CCE budget defined in Rel-15 is kept?

Companies are encouraged to provide comments in the table below.

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

Q6: Whether the fields in the single DCI which schedules the two PDSCHs on two carriers are shared or separate for each PDSCH?

Companies are encouraged to provide names for each field in the corresponding column of the below table.

**Table 1: Fields in the DCI which can schedule two PDSCHs on two carriers**

|  |  |  |
| --- | --- | --- |
| DCI fields | Shared indication for the two scheduled PDSCHs | Separate indication for each scheduled PDSCH |
| Identifier for DCI formats |  |  |
| Carrier indicator |  |  |
| Bandwidth part indicator |  |  |
| Frequency domain resource assignment |  |  |
| Time domain resource assignment |  |  |
| VRB-to-PRB mapping |  |  |
| PRB bundling size indicator |  |  |
| Rate matching indicator |  |  |
| ZP CSI-RS trigger |  |  |
| Modulation and coding scheme |  |  |
| New data indicator |  |  |
| Redundancy version |  |  |
| HARQ process number |  |  |
| Downlink assignment index |  |  |
| TPC command for scheduled PUCCH |  |  |
| PUCCH resource indicator |  |  |
| HARQ timing indicator |  |  |
| Antenna port(s) |  |  |
| Transmission configuration indication |  |  |
| SRS request |  |  |
| CBGTI |  |  |
| CBGFI |  |  |
| DMRS sequence initialization |  |  |
| 24-bit CRC |  |  |

## 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** |
| Vivo | *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* |
| 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 6: HARQ-ACK feedback for the two PDSCHs scheduled by a single DCI is included in same HARQ-ACK codebook.* |

Q7: Whether HARQ-ACK codebook determination needs to be enhanced when multiple PDSCHs are scheduled by a single DCI?

Companies are encouraged to provide comments in the table below.

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

## Other issues

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

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

# Miscellaneous (Low priority)

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

|  |  |
| --- | --- |
| Company | Key Proposals/Observations |
| Huawei, HiSilicon | *Observation 11: Using single DCI scheduling multi-carriers has large potential to be deployed with other NR features, deployment scenarios and services.* |
| 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 3: Both 1-stage DCI aggregation and 2-stage DCI aggregation for cross-carrier scheduling should be included for the evaluation. |
| ETRI | Observation 5: For multi-cell joint scheduling, scheduling more than two cells using a joint 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).* |

Discussion points:

One company [13] propose both 1-stage DCI aggregation and 2-stage DCI aggregation for cross-carrier scheduling. For 1-stage DCI, DCIs for the scheduled cells are aggregated into a 1-stage DCI in a PDCCH. For 2-stage DCI, DCIs for the scheduled cells are aggregated into a 2-stage DCI, where 1st stage DCI is carried in a PDCCH and 2nd stage DCI is carried in a set of REs indicated in the 1st stage DCI.

Q8: Whether to support two-stage DCI for scheduling multiple carrier PDSCHs?

Companies are encouraged to provide comments in the table below.

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

Discussion point:

Q9: Whether to support more than 2 carriers scheduled by a single DCI?

Companies are encouraged to provide comments in the table below.

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

Q10: Whether to support multiple PDSCHs on same carrier scheduled by a single DCI?

Companies are encouraged to provide comments in the table below.

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

Q11: Whether to support multiple PUSCHs on multiple carriers scheduled by a single DCI?

Companies are encouraged to provide comments in the table below.

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

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