**3GPP TSG RAN WG1 #112bis-e Draft R1-2303788**

**e-Meeting, April 17th – April 26th, 2023**

**Agenda Item: 9.12.3**

**Source: Moderator (InterDigital, Inc.)**

**Title: [Draft] Summary #1 on dynamic switching between DFT-S-OFDM and CP-OFDM**

**Document for: Discussion and Decision**

# Introduction

RAN approved a WI on further coverage enhancements for NR [1]. The WI includes the following objective:

* *Specify enhancements to support dynamic switching between DFT-S-OFDM and CP-OFDM (RAN1)*

The WI also includes corresponding justification point:

* *DFT-S-OFDM waveform is beneficial for UL coverage limited scenario because of its lower PAPR compared with CP-OFDM waveform. Currently, UL waveform is configured via RRC and this limitation imposes a large barrier to switch over to DFT-S-OFDM waveform for cell-edge UEs practically.*

This contribution summarizes contributions submitted in RAN1#112 under AI 9.14.3 – Dynamic switching between DFT-S-OFDM and CP-OFDM.

Here is the color code used in this summary:

* **FL observations**
* **FL proposals**
* **Questions for the inputs from companies**
* **FL summary based on the companies’ input**
* **RAN1 agreements**

A tag ([Open]/[Closed]) is indicated for each issue for each round of discussion. For a given round, input is requested for issues marked as [Open] only. In addition, a [LP]/[MP]/[HP] tag indicates envisioned priority of each issue in this meeting.

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# Collection of agreements in RAN1#112bis-e

[TBD]

# Proposals

## Proposals for 1st GTW/checkpoint

## Proposals for 2nd GTW/checkpoint

## Proposals for 3rd GTW/checkpoint

# Topic #1: Applicability of dynamic waveform switching

A set of issues is related to the type of transmission concerned by dynamic waveform switching.

In RAN1#110bis-e, RAN1 made agreement that dynamic waveform switching is applicable to PUSCH channel only. RAN1 made a further agreement that it is applicable to PUSCH dynamically scheduled by DCI format 0\_1 or 0\_2. In RAN1#112, RAN1 agreed that dynamic waveform switching is not applicable to PUSCH transmissions with a Type 1 configured grant and concluded that there is no consensus to support PUSCH transmissions with a Type 2 configured grant.

The following cases are considered separately:

* PUSCH dynamically scheduled by C-RNTI with DCI format 0\_0
* Msg3 PUSCH scheduled by RAR or by TC-RNTI with DCI format 0\_0
* Other cases/scenarios

## [LP][Open] Issue #1-1: Applicability to PUSCH scheduled by C-RNTI with DCI format 0\_0

**Summary of company views from contributions submitted to RAN1#112bis-e**

Applicability to PUSCH scheduled by C-RNTI with DCI format 0\_0

Yes: Oppo [4], ZTE [7], Nokia [10], Mavenir [15]

[Justifications]

* No ambiguity after the UE is connected to network [4]
* Need to maximize applicability of dynamic waveform switching [7]
* DCI format 0\_0 is used in coverage-limited scenarios [4][7][10][15]
* Always configuring DFT-S-OFDM for DCI format 0\_0 inefficient [7]
* Using DFT-S-OFDM more resource-efficient than using PUSCH repetitions [10]

[Proposed solutions]

* Add 1 bit [15] if number of bits for DCI format 0\_0 before padding is smaller than DCI format 1\_0 [7]
* Add column to default TDRA table [4]

Open: NTT DOCOMO [28]

* Cannot use 1 additional bit in DCI [28]

No: Spreadtrum [5], CATT [6], Intel [8], InterDigital [12], China Telecom [13], Panasonic [14], Lenovo [16], ETRI [18], CMCC [19], Mediatek [20], Qualcomm [23], Sharp [24], Ericsson [26], LG [29]

* Supporting format 0\_0 has small benefit, e.g. other formats can be used [6][12][20]
* Can configure DFT-S-OFDM for format 0\_0 if coverage is limited [12]
* Better if interpretation remains stable during RRC reconfiguration [5][12][13][18]
* Better not to increase payload size of DCI format 0\_0 [16][14][8][18][19][23][26], cannot change size for CSS [14][24]
* Format 0\_0 only has mandatory fields, should not add bit [5]
* Format 0\_0 only supports basic scheduling/fallback operation [8][13][16][19][23], e.g. only RA type 1 [5][6], DMRS configuration/port is fixed [5].
* Indication in DCI format 0\_1 or 0\_2 cannot be used to indicate subsequent transmissions [5]
* Would require different solution for this DCI format [23][29], significant specification impact [13]

**Observations on applicability to PUSCH scheduled by C-RNTI with DCI format 0\_0**

4 companies support applicability to PUSCH scheduled by C-RNTI with DCI format 0\_0. 1 company is open. On the other hand, 14 companies do not support any applicability to PUSCH scheduled by DCI format 0\_0.

Majority of companies think there is little, or no benefit given that other formats can be used, and that this DCI format is intended for basic operation and for robustness during RRC reconfiguration. There are also concerns about introducing a field linked to an optional feature to this format and potentially increasing the size.

Moderator does not see how further discussion can change the situation for this issue, and recommends taking the following conclusion:

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| **FL proposed conclusion 1-1**: For PUSCH transmission scheduled by C-RNTI with DCI format 0\_0, UE considers transform precoding enabled or disabled according to *msg3-transformPrecoder* as in legacy. |

### 1st round

Please indicate if your company position was incorrectly captured or if you would like to add your company position to the summary above. Please feel free to provide any feedback on FL proposed conclusion 1-1:

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## [LP][Open] Issue #1-2: Applicability to msg3 PUSCH

**Summary of company views from contributions submitted to RAN1#112bis-e**

Applicability to PUSCH scheduled by RAR and/or by TC-RNTI with DCI format 0\_0

* Yes**:** Oppo [4], ZTE [7], Intel [8], Sony [9], Nokia [10], (Panasonic [14]), Mavenir [15]

[Justification]

* + Enables selection based on UE’s channel conditions instead of cell-level [4][8][10]
  + Improve reliability of msg3 retransmission [8]
  + Other msg3 coverage enhancement techniques not sufficient [9]
  + Cell-level configuration is not always DFT-S-OFDM [10]
  + Support for msg3 retransmission even more important than initial transmission [10]
  + Msg3 repetitions may not be sufficient [10]

[Proposed solutions]

* + Add column to default TDRA table [4]
  + Set waveform to DFT-S-OFDM if number of repetitions is >1 [7]
  + Same waveform for msg3 initial transmission (RAR) and retransmission (TC-RNTI) [7]
  + Override SIB field for UE in connected or inactive mode [9]
  + Indicate in MAC CE or PDCCH order for RACH for UE in connected/inactive state [9]
  + Use reserved bits or CSI request bit of RAR for idle state UE [9]
  + Use DFT-S-OFDM if using/capable of multiple PRACH transmissions [9]([10])[14]
  + Solution should not impact DCI format 0\_0 [10][13]
  + Add 1 bit to DCI format 0\_0 [15]
* Study: NTT DOCOMO [28]
  + Cannot use 1 additional bit in DCI [28]
* No**:** Spreadtrum [5], CATT [6], InterDigital [12], Lenovo [16], Samsung [17], CMCC [19], Mediatek [20], Qualcomm [23], Ericsson [26], LG [29]
  + Additional preamble partitioning required [5][6][12]
  + gNB does not have sufficient channel/power information to select [5][16][17][19][23][26]
  + Would require PRACH resources for identification of capability [17][23]
  + Difficult to introduce indication in RAR and DCI format 0\_0 [6][19][29]
  + Msg3 repetitions are specified and sufficient, latency not a concern [23]
  + Unclear benefit [6][20], gain of using CP-OFDM for msg3 PUSCH is small [12]

In addition, no company proposes to support dynamic indication for msgA, and two companies [5][6] explicitly proposes to not support it.

**Observations on applicability to msg3 PUSCH**

7 companies support applicability to msg3 PUSCH for either or both initial transmission by RAR or retransmission by TC-RNTI with DCI format 0\_0. 1 company is open to study. 10 companies do not support. Non-supporting companies think that the benefit is unclear given that the network has not enough information on the UE situation and have concerns about complexity of supporting indication from RAR or DCI and potential additional RACH partitioning required for indication of capability.

A few companies suggested that the selection of waveform could be tied to the capability or use of PRACH repetitions to be supported in R18. The simplest solution would be that a UE that uses PRACH repetitions also uses DFT-S-OFDM for the transmission or retransmission of msg3. In moderator’s understanding, this solution could address concerns about reliability of msg3 transmission for UE’s capable of PRACH repetition while not requiring any other mechanism for the capability or waveform indication. Thus, it may be worth considering as a potential compromise. This is reflected by the proposal below.

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| **FL proposal 1-2**: For PUSCH transmission scheduled by RAR or TC-RNTI with DCI format 0\_0, UE considers transform precoding enabled or disabled according to *msg3-transformPrecoder* as in legacy at least if the UE does not use multiple PRACH transmissions in RACH procedure.   * FFS: UE enables transform precoding for PUSCH transmission scheduled by RAR or by TC-RNTI with DCI format 0\_0 if the UE uses multiple PRACH transmissions in RACH procedure. |

### 1st round

Please indicate if your company position was incorrectly captured or if you would like to add your company position to the summary above. Please feel free to provide any feedback on FL proposal 1-2.

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## [LP][Open] Issue #1-3: Other issues related to requirements and scenarios

**Summary of company views from contributions submitted to RAN1#112bis-e**

For the scenario of uplink carrier aggregation:

* Nokia [10] proposes to further study whether/how DWS feature is enabled for UL CA
  + Largest MPR is considered for intra-band contiguous CA, CC in poor coverage cannot take advantage of larger Pcmax
* Panasonic [14] proposes to discuss whether dynamic waveform switching is supported in CA/DC scenario.
  + Dynamic waveform switching is to be used not in real cell edge but closer to the cell center, therefore should be supported [14]
* Mavenir [15], Ericsson [26] propose that UL CA is assumed to be supported with dynamic waveform switching
  + R17 coverage enhancements features can all be supported in UL CA scenario.
* Ericsson [26] proposes to study whether/how the power sharing across UL carriers affects UL transmission power after waveform switching.

Configured grant type 2

Sony [9] and Mavenir [15] proposes to adopt dynamic waveform switching for Type 2 CG-PUSCH:

* For CG re-activation when a new talk spurt occurs [9]
* Can be used for URLLC, small specification effort [15]

Other

* Spreadtrum [5], LG [29] propose that PUSCH transmission in RRC-connected can support dynamic waveform switching.
* Nokia [10] proposes to further study whether/how DWS feature is enabled for mTRP scenario.

**Observations on other issues related to requirements**

Moderator assumes that dynamic carrier switching is supported in uplink carrier aggregation, although it does not imply that dynamic waveform switching indication will be supported in DCI format 0\_X.

### 1st round

Please indicate if your company position was incorrectly captured or if you would like to add your company position to the summary above.

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# Topic #2: Dynamic switching mechanism

## [HP][Open] Issue #2-1: DCI size alignment between CP-OFDM and DFT-S-OFDM

**Summary of company views from contributions submitted to RAN1#112bis-e**

Option 1: Per-format

* Preferred or acceptable: Huawei [2], InterDigital [12], (Samsung [17]), (Ericsson [26]), (NEC [27])

[Impact on DCI construction/parsing][2][8][12][26]

* + Only requires bit padding at end of DCI [2]
  + Reuse current DCI decoding scheme, lower UE implementation complexity [2][8]
  + DWS indication precedes any field of the DCI format that has waveform-dependent size [2][17], precedes NDI field [17]
  + Can ensure that fields before NDI (e.g. FDRA) are aligned by specification [12]
  + Do not configure simultaneously with Type 0 resource allocation to avoid waveform-dependent fields before NDI [26]
  + Same principle as cross-carrier scheduling [2]
  + Would not prevent usage of CG type 2 PUSCH [2], UE needs to parse DWS field for CG retransmission anyway [2]

[Potential size benefit if new fields are introduced][2][12][27]

* + Easy to introduce new fields, e.g. FDSS for DFT-S-OFDM, smaller DCI size [2][12]
  + Beneficial if there is one field that is larger for DFT-S-OFDM compared to CP-OFDM [27]
* Concerns: OPPO [4], Spreadtrum [5], ZTE [7], Nokia [10], Apple [22], Qualcomm [23], Google [25], NTT DOCOMO [28]

[Impact on DCI construction/parsing][4][5][7][8][10][22][23]

* + New 1-bit field needs to be in the beginning of format (or after NDI) [4][5][8][10]
  + Potential additional complexity when considering other features [23], e.g. multi-cell scheduling [8][23], multi-PUSCH scheduling [23], dynamic switching of TRP transmission modes [23]
  + Requires reading DWS bit before parsing [5][23], adding more features with dynamic DCI parsing increases complexity of DCI decoding [23]
  + FDRA field is before NDI and may have size that depends on resource allocation type configuration [5]([10])[22]
  + Alt-B requires that waveform-dependency of field size is not introduced in future releases before NDI [7][10]
  + *[Additional concerns/observations on decodability of DCI scrambled by CS-RNTI [10] – however moderator thinks they may not be correct because we have alignment between C-RNTI and CS-RNTI]*

[DCI size benefit unclear or negligible][4][5][7][8][24][25][29]

* + UL DCI typically smaller than DL DCI [5][8]
  + Not much difference between payload of CP-OFDM and DFT-S-OFDM in practice because CP-OFDM will use small rank [18]
  + Negligible overhead decrease even if some fields are larger for DFT-S-OFDM in future [24]
  + New field specific to DFT-S-OFDM is hypothetical [29]

Option 2: Per-field

* Preferred or acceptable: vivo [3], OPPO [4], Spreadtrum [5], CATT [6], Intel [8], Nokia [10], (InterDigital [12]), China Telecom [13], Panasonic [14], Lenovo [16], (Samsung [17]), ETRI [18], Transsion [21], Sharp [24], Google [25], (Ericsson [26]), (NEC [27]), NTT DOCOMO [28], LG [29]

[Lower complexity, more robust approach]

* + Clean solution with impact limited to few relevant fields, less complex/risky than per-format [4][6][7][13][14][16][22][23][29]
  + DCI construction invariant to selection of transmission waveform [23]
  + Lower specification effort [5][10][25]
  + No restriction on either position of DWS field nor field size before/after NDI field, more flexible and forward compatible design [3][8][10][16][25]
  + Same principle as for BWP switching, per-field alignment between current and target BWP [8][18]
  + Compatible/pairs well with alignment between CS-RNTI and C-RNTI [5][14][23]
  + Minimize the impact of DWS on type 2 CG PUSCH and its activation/deactivation [28]
  + No additional size comparison step needed between DCIs with different NDI values [29]

[Lower impact to UE implementation]

* + Least disruptive to UE implementation, CG-PUSCH already deployed in the field [23]
  + Can still position new field in front to help parsing other fields [4][5], avoids two passes of parsing and decoding [5]

[New field specific to DFT-S-OFDM]

* + Can leverage zero-padded bits to avoid larger DCI size if new DFT-S-OFDM specific field is introduced in future [10]
  + Beneficial if it is not expected that there is one field that is larger for DFT-S-OFDM compared to CP-OFDM [27]
* Concerns: Huawei [2]
  + Padding bits cannot be reused by new fields [2]
  + Larger DCI size when new fields are introduced in DCI only for DFT-S-OFDM [2]
  + Requires change to current DCI decoding scheme, increases implementation complexity of UEs [2]

Option 3: Per-field alignment for fields preceding NDI field

* Preferred: CMCC [19]
  + Same advantage as Option 1 if a new field is introduced for DFT-S-OFDM [19]
  + Almost all fields influenced by waveform are located after NDI
* Concerns: Huawei [2], Spreadtrum [5], CATT [6], ZTE [7], Nokia [10], Apple [22], Qualcomm [23]
  + More complex, requires both per-field and per-format [2][5][7][22][23]
  + CG type 2 PUSCH is optional feature, should not impact gNBs and UEs that do not implement it [2]
  + May impact PDCCH validation [5](?)
  + Unclear benefit [5][7]
  + Not relevant if fields preceding NDI are not waveform-dependent [6]
  + Larger DCI size compared to option 1 [10]

Option 4: Per-field alignment only for DCI addressed to CS-RNTI

* Preferred: Mediatek [20]
  + Current spec follows per-format alignment for DCI with C-RNTI and per-field alignment for DCI with CS-RNTI [20]
* Concerns: Huawei [2], Spreadtrum [5], ZTE [7], Nokia [10], InterDigital [12], Apple [22], Qualcomm [23], Sharp [24]
  + More complex, uses two DCI alignment methods [2][5][7][12][22][29]
  + Unclear benefit [5][6][7]
  + May remove Option 1 benefit of potentially smaller field size [5]
  + Fields need to have size for CP-OFDM at least equal to size for DFT-S-OFDM otherwise cannot be used for CS-RNTI and NDI=1 [6][10], limitation undesirable [24]
  + DWS field need to be located before first waveform-dependent field [10]
  + Would end up creating two classes of DG-PUSCH [23]
  + If DWS is disabled, DCI for CS-RNTI fallbacks to legacy mode – effectively becomes new DCI format [23]

Other proposals

* Huawei [2] proposes to use 0 and 1 to indicate the waveforms.
* Nokia [10] proposes Option 5: Per-format alignment for DCI addressed to C-RNTI, per-field alignment for CS-RNTI depending on latest DWS waveform indicated by DCI scrambled by CP-OFDM
* Nokia [10] proposes that DCI contains DWS field only within certain time periods only to avoid overhead
  + Panasonic [14] has concerns on complexity and thinks it is not needed.
* [4][10] provides a list of waveform-dependent fields:
  + FDRA, TPMI, Second precoding information, Antenna ports, PTRS-DMRS association, Second PTRS-DMRS association, DRMS sequence initialization
* Sharp [24] thinks it needs to be clarified whether FDRA field size should be set according to *resourceAllocation* for both waveforms, or not [24]
* LG [29] proposes that if CG-PUSCH Type 2 is configured, waveform to be applied should be decided upon its DWS field availability and NDI values at UE.

**Observations on DCI size alignment**

Per-format alignment (Option 1) is preferred by at least 2 companies. 2 other companies did not explicitly express preference in their contributions, but proposals implicitly assume per-format alignment. On the other hand, 8 companies expressed concerns about this option.

Per-field alignment (Option 2) is preferred by 15 companies seems acceptable to 19 companies. 1 company expressed concerns about this option.

In general, companies analyzed the Options on the table from perspective of complexity, forward compatibility, and efficiency.

From the perspective of complexity, majority of companies believe that per-field alignment is generally simpler than per-format alignment because it does not require decoding the DWS field before parsing other fields. Introducing such dependency to the DCI encoding/decoding process is also foreseen to increase the potential for issues when introducing new features in the future. Potential dependency of the position of the NDI field is a drawback from UE perspective because it impacts PDCCH validation for configured grant type 2 activation/release. To address this problem, one sub-option of per-format alignment (Alt. B) imposes condition that no field preceding NDI field has a size that depends on the DWS field. This could be done by aligning fields such as FDRA if necessary. However, companies still have concerns that this is not a robust approach as the condition would have to be maintained in future releases.

From the perspective of efficiency, per-format alignment is more optimal since it guarantees the smallest number of padding bits required for alignment. However, majority of companies noted that this benefit does not exist in practice with currently defined fields since all of them have larger size for one waveform (CP-OFDM). This situation may change if new fields specific to DFT-S-OFDM are introduced, but even if this occurs the overhead benefit is likely to be very small or zero (e.g. if UL DCI is still smaller than DL DCI).

Option 3 and Option 4 were developed as potential compromise solutions during RAN1#112 offline discussions. However, only 1 company showed support for each Option while 7 and 8 companies (respectively) expressed concerns. The concerns are that these solutions further increase complexity by using both alignment methods.

Considering majority view, moderator recommends agreeing on per-field alignment (Option 2).

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| **FL proposal 2-1**: For DCI format 0\_1/0\_2 containing dynamic waveform indication, bit width of each field is set to the maximum between the bit width of the field if transform precoding is disabled and the bit width of the field if transform precoding is enabled, if different.   * If, for the waveform indicated in the DCI, the bit width N of a field would be smaller than the bit width of the field set as per the above, UE decodes the field using N least significant bits. If N=0, the UE ignores the field for the indicated waveform. |

### 1st round

Please indicate if your company position was incorrectly captured or if you would like to add your company position to the summary above. Please feel free to provide any feedback on FL proposal 2-1.

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## [MP][Open] Issue #2-2: Handling of FDRA type/DMRS type

**Summary of company views from contributions submitted to RAN1#112bis-e**

FDRA type

Several companies [3][5][6][10][12][19][25][28] discuss options for handling of FDRA type configuration when dynamic waveform switching indication is configured, considering that FDRA type 0 is not supported for DFT-S-OFDM. The following alternatives are identified:

* Option 1: *resourceAllocation* set to *resourceAllocationType0* is error case: [5][6][19][28]
  + MSB of FDRA set to 0 is error case if DFT-S-OFDM is indicated and FDRA type is set to dynamicSwitch [28]
* Option 2: If DFT-S-OFDM is dynamically indicated, UE applies type 1 resource allocation regardless of how *resourceAllocation* is set or how dynamic indication of FDRA type is set ([6])[10][12][25].

[Benefits]

* + Works regardless of whether the resource allocation type is RRC configured or dynamically indicated and regardless of DCI size alignment solution [10]
  + Does not require setting *resourceAllocation* to *dynamicSwitch* when network wants to use type 0 for CP-OFDM, saves 1 bit [12]

DMRS type

Two companies [6][28] discuss handling of DMRS type when dynamically waveform switching indication is configured, considering that DMRS type 2 is not supported for DFT-S-OFDM. The following alternatives are identified:

* Option 1: *dmrs-Type* set to *type2* is error case
* Option 2: If DFT-S-OFDM is dynamically indicated, UE applies DMRS type 1 regardless of how *dmrs-Type* is set.

Other waveform-specific configuration aspects

Vivo [3], Spreadtrum [5] discuss the potential issue of indicating rank>1 with DFT-S-OFDM.

Vivo [3] proposes to discuss rules to avoid indicating a waveform not supported with pi/2 BPSK.

Spreadtrum [5] proposes that parameters required by both waveforms are configured when dynamic waveform switching is configured.

Spreadtrum [5] proposes to apply MCS table configured for indicated waveform.

**Observations on handling of FDRA type, DMRS type and other waveform-specific configuration aspects**

The alternatives for the handling of FDRA type are to (1) consider that a configuration or indication incompatible with DFT-S-OFDM (i.e. Type 0) is an error case or (2) ignore the configuration when DFT-S-OFDM is indicated and use Type 1 resource allocation. In moderator’s understanding, the issue only exists for the case where *useInterlacePUCCH-PUSCH* is not configured since otherwise resource allocation type 2 is used regardless of how *resourceAllocation* IE is set. This leads to the following proposal:

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| **FL proposal 2-2**: For PUSCH scheduled by DCI format 0\_1/0\_2 with dynamic waveform switching indication field configured, and *useInterlacePUCCH-PUSCH* is not configured, downselect between following options:  Option 1 (configuration restriction with error case handling):   * If DFT-S-OFDM is indicated, UE does not expect *resourceAllocation* set to *resourceAllocationType0*. * If DFT-S-OFDM is indicated and *resourceAllocation* set to *dynamicSwitch*, UE does not expect MSB of FDRA field set to 0.   Option 2 (UE only uses *resourceAllocation* if CP-OFDM is indicated):   * If DFT-S-OFDM is indicated, UE applies type 1 resource allocation. * If CP-OFDM is indicated, UE applies resource allocation according to *resourceAllocation* IE. * Size of FDRA field is aligned between size for type 1 resource allocation and size according to *resourceAllocation* IE. |

For DMRS type, same options are identified:

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| **FL proposal 2-3**: For PUSCH scheduled by DCI format 0\_1/0\_2 with dynamic waveform switching indication field configured, downselect between following options:  Option 1 (configuration restriction with error case handling):   * If DFT-S-OFDM is indicated, UE does not expect *dmrs-Type* to be set to *type2*.   Option 2 (UE only uses *dmrs-Type* if CP-OFDM is indicated):   * If DFT-S-OFDM is indicated, UE applies DMRS type 1. * If CP-OFDM is indicated, UE applies DMRS type according to *dmrs-Type*. |

### 1st round

Please indicate if your company position was incorrectly captured or if you would like to add your company position to the summary above. Please feel free to provide any feedback on FL proposals 2-2 and 2-3.

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## [LP][Open] Issue #2-3: DCI indicating multiple TBs

**Summary of company views from contributions submitted to RAN1#112bis-e**

Several companies [3][7][8][14][28] discuss whether/how to support dynamic switching indication in case a DCI schedules multiple TBs. Different cases are identified.

Multiple TBs/PUSCHs scheduled in time domain by single DCI for one serving cell [3][8][14][28]

* This case corresponds to multi-PUSCH scheduling using DCI format 0\_1 for shared spectrum access.
* Option 1: Common 1-bit DWS indication for all PUSCHs
  + Intel [8], Panasonic [14], NTT DOCOMO [28]
  + The multiple PUSCH typically experience similar channel conditions and scheduler cannot predict change anyway [28]
* Option 2: N-bit DWS indication for N PUSCHs
  + Vivo [3]

Multiple TBs/PUSCHs on multiple serving cells scheduled by single DCI (format 0\_X)

* Support DWS indication in format 0\_X?
  + Yes: Intel [8] (FFS bits), (vivo [3]), ZTE [7]
  + Discuss in multi-carrier AI: Panasonic [14]
* One or multiple DWS?
  + Multiple bits: vivo [3]
  + Single bit: ZTE [7]
    - Unified solution with single TB/single DCI
    - Can use DFT-S-OFDM (more conservative) or majority waveform (?)
    - Less overhead, less specification effort

2 TBs on single serving cell with 8Tx UL transmission

* Dynamic waveform switching indication not applied because rank>1: ZTE [7]
* Discuss in MIMO AI: Panasonic [14]

**Observations on DCI indicating multiple TBs**

In general, not many companies contributed on these issues as the focus is on the completion of single TB case.

For the case of multi-PUSCH scheduling in time domain using DCI format 0\_1 for shared spectrum access, 3 companies think it should be supported with single-bit DWS field indicating single waveform applicable to all PUSCHs. 1 company thinks it should be supported with multi-bit DWS field indicating waveform to respective multiple PUSCHs. From moderator’s perspective, it seems that single waveform indication applicable to all PUSCHs would be sufficient for this case and same solution as for single TB can be reused without any issue. The following is therefore proposed:

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| **FL proposal 2-4**: For UE configured with multi-PUSCH scheduling in time domain *(*i.e. *pusch-TimeDomainAllocationListForMultiPUSCH*), DCI format 0\_1 supports 1-bit field for dynamic waveform switching indication.   * When configured, 1-bit field indicates waveform for all scheduled PUSCH transmissions. |

For the case of multiple PUSCHs on multiple serving cells scheduled by DCI format 0\_X, 3 companies think that DWS should be supported for this case. One company thinks a single DWS bit should indicate single waveform applicable to multiple serving cells, while another company thinks multiple bits are required. During RAN1#112, majority of companies indicated that discussion on supporting DCI format 0\_X should be lower priority.

For the case of 2 TBs with 8Tx UL transmission, one company indicates that DWS indication should not be configured because DFT-S-OFDM does not support rank > 1. Moderator thinks it may depend on whether fallback to 1 TB is supported for this feature. More progress seems needed in MIMO AI before potential applicability of DWS can be discussed for this case.

### 1st round

Please indicate if your company position was incorrectly captured or if you would like to add your company position to the summary above. Please indicate if FL proposal 2-4 is agreeable.

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| Company | Comments |
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## [LP][Open] Issue #2-4: Other issues

**Summary of company views from contributions submitted to RAN1#112bis-e**

Two companies [3][18] discuss handling of BWP switching when dynamic waveform switching indication is configured.

* [18] proposes that in case UE switches from a BWP not configured with DWS to a BWP configured with DWS, the 1-bit field for DWS indication is taken from existing field (e.g. MCS).
* [3] proposes to apply RRC-configured waveform of target BWP for PUSCH scheduled by DCI indicating BWP change irrespective of dynamic switching indication in DCI.

Oppo [4] proposes that in configured grant, the PUSCH transmissions other than scheduled by DCI format 0\_1 or 0\_2 in PDCCH scrambled by CS-RNTI with NDI=1 should follow the waveform of the earlier transmission.

CMCC [19] proposes to study potential enhancement to enable UE fallback from DWS to legacy DCI.

Samsung [17] proposes to study whether additional timeline is needed for UL scheduling in case of dynamic waveform switching.

Samsung [17] proposes to study whether enhancement is needed for UCI multiplexing in case a PUCCH overlaps with multiple PUSCHs with different waveforms.

**Observations on other aspects**

In moderator’s understanding, the above issues are of lower priority or can be addressed later, e.g.:

* For BWP switching, it should first be decided if DWS is configured per BWP or UE.
* The waveform for CG retransmission is determined according to DWS indication as per RAN1#110bis-e and RAN1#112 agreements.
* Moderator does not expect that timeline relaxation would be needed based on input from companies during RAN1#110bis-e. However, companies are welcome to provide input on this issue.

### 1st round

Please indicate if your company position was incorrectly captured or if you would like to add your company position to the summary above.

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| Company | Comments |
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# Topic #3: Assistance information for switching waveform

## [HP][Open] Issue #3-1: Assistance information for switching waveform

**Summary of company views from contributions submitted to RAN1#112bis-e**

Support assistance information for a target waveform (“pre-switch assistance”)?

* Yes: Huawei [2], Spreadtrum [5], vivo [3], Xiaomi [11], InterDigital [12], China Telecom [13], Panasonic [14], NEC [27], Lenovo [16], ETRI [18], Ericsson [26], Transsion [21], Apple [22], NTT DOCOMO [28], Nokia [10], Qualcomm [23]
  + Difference of Pcmax between waveforms function of UE implementation [2][5][12][21]
  + Data transmission failure may occur if gNB estimate of power boosting is optimistic [2]
  + Limited performance improvement without enhancement as scheduler cannot decide MCS and RB allocation when switching waveform without power difference info [2][22]
  + gNB may blindly switch back and forth without assisting information [10]
  + Help gNB decide when to trigger waveform switch based on how much additional power a UE can deliver using alternate waveform [23][28]
  + Power headroom related information based on Pcmax,f,c of target waveform [26]
  + Help gNB schedule PUSCH transmission with target waveform properly by providing accurate FDRA and MCS [26]
* Maybe/study: Mediatek [20]
  + Need to quantify potential performance gains considering additional overhead [20]
* No: Oppo [4], ZTE [7], Mavenir [15], Samsung [17], Google [25]
  + Existing PHR sufficient, should be justified by simulation results [4]
  + Unclear benefit [7][17][25], large effort for a simple feature [17][25]
  + gNB can estimate rough difference of PHR between waveforms based on current PHR, SRS estimation or other measurement after waveform switching [7]
  + gNB can learn based on storing history of PHR data [7]
  + Increases overhead of UL signaling and reduces coverage [7]
  + gNB knows whether the UE is at cell edge or in cell center [15]
  + Dynamic switching does not increase need for enhancement compared to RRC switching [15][17]
  + Not required by WID objective [17]

Assumptions for reference PUSCH (RB allocation, MCS) when reporting PH for a target waveform?

* Same as current PUSCH: Huawei [2], Spreadtrum [5], Xiaomi [11], InterDigital [12], Panasonic [14], Transsion [21], Apple [22], Qualcomm [23]
  + Need to adjust in case RB allocation not supported for target [14]
* Assume a default value if actual PUSCH RB allocation not compatible with target waveform: Spreadtrum [5]
* Same inner/outer/edge RB allocation and modulation order as actual PUSCH transmission: Ericsson [26]
* Reuse legacy type 1 PHR based on actual PUSCH but Pcmax is based on target waveform: Ericsson [26]
* Consider MPR, A-MPR and P-MPR when computing PH [23]
* Consider both cases, same or different RB allocation and modulation order [10]
  + To provide precise PH related information of target waveform in different RB regions or for different modulations.
* Virtual PH:
  + No PH for target waveform in that case: vivo [3], Lenovo [16]
* Assistance information can include Pcmax/PH for target waveform or Pcmax/PH difference between waveforms [5]

Enhance PHR MAC CE to include assistance information?

* Yes: (vivo [3]), (InterDigital [12]), ETRI [18], (Ericsson [26]?), Apple [22], Qualcomm [23], (NTT DOCOMO [28]), Nokia [10], China Telecom [13]
  + Reuse R17 PUSCH repetition solution (two PHs in single MAC CE) [18]
  + Report both PH’s (easier gNB implementation) [22][28]
  + Report Pcmax and PH for both waveforms [23]
  + Option 1: both PHRs, Option 2: current PH + PH difference of target [10]
* No: Huawei [2]
  + Information only useful for limited period of time, high overhead [2]
  + Better to include only for target waveform when necessary [2]

Triggering of assistance information or new PHR trigger

* Network request: (Huawei [2]), InterDigital [12], NTT DOCOMO [28]
  + Helps gNB make timely waveform switching decision and adjust resource allocation and MCS selection, but requires additional overhead [2]
  + Better scheduling flexibility [12]
  + Obtain PHR information in timely manner [28]
* PH value becoming higher (lower) than a threshold: Xiaomi [11], NEC [27], InterDigital [12], Transsion [21], Qualcomm [23]
  + PH for CP-OFDM becomes higher than X1 while DFT-S-OFDM is used [27]
  + PH for DFT-S-OFDM becomes lower than X2 while CP-OFDM is used [27]
  + PH becomes lower than threshold and another waveform with better PH is available [23]
  + Concerns: Huawei [2]
    - Cannot help gNB make waveform switching decision [2]
    - May result in too frequent PH reporting [2]
* Waveform has switched (“post-switch assistance”): Huawei [2] (existing PHR), ZTE [7] (existing PHR only), China Telecom [13], CMCC [19], Nokia [10], (Mavenir [15]), Google [25]
  + PHR uses current calculation method [2]
  + Help gNB indicate suitable RB allocation and MCS index after waveform switching [2]
  + gNB can use the information to learn error [7]
  + Send PHR in next uplink transmission after waveform switching [7]
  + After expiry of timer to avoid unnecessary overhead [10]
  + Only if there is change in PL and change in PL difference between waveforms compared to previous report [10]
  + Simplest way to help gNB better evaluate PAPR reduction under different waveforms [25]
* Reuse existing trigger [add assistance info to PHR]: vivo [3], Spreadtrum [5], InterDigital [12], Ericsson [26], Apple [22]
  + Waveform not supposed to change very frequently, existing events sufficient [26]
  + Support shorter values of periodic PHR timer: Apple [22]
  + Additional conditions for including assistance information: vivo [3], Spreadtrum [5], InterDigital [12]
    - Change of waveform since last PUSCH transmission [3]
    - RSRP less than threshold or current path loss is larger than previous moment and exceeds a threshold [5]
    - PH is lower than a threshold [12]
    - PH difference between waveforms is higher than a threshold [12]
* Continuous data error compared with a threshold: Xiaomi [11]
* No enhancement: Oppo [4], Samsung [17]
  + Existing triggering sufficient, should be justified by simulation results [4]
  + Benefit unclear, large effort for a simple feature [17]
  + Not required by WID objective, not specific to dynamic switching (would have been applicable to RRC-based switching) [17]

Recommended waveform or request to switch waveform

* Yes: Spreadtrum [5], Xiaomi [11]
* No: Huawei [2], Ericsson [26]
  + Requires new MAC CE [2]
  + Not helpful to decide MCS selection and RB allocation [2]
  + UE recommended waveform may be based on particular RB allocation and modulation order (current transmission) which gNB may change [26]

Other proposals

* UE reports power reduction due to waveform switching in UE capability reporting [19]
* Discuss scenario when report of PHR for current and target waveforms is close to or overlaps with existing PHR of current waveform [10]
* Study reporting of PHR information considering CA/DC scenario [14]
* Support smaller values of prohibit timer for PHR [15]
* PHR for a target waveform determined from an actual PUSCH using same waveform or reference PUSCH in case no PUSCH uses same waveform [16]
* Support independent open-loop power control parameter for each waveform [29]
  + To immediately change the transmission power after changing waveform [29]

**Observations on assistance information**

From moderator’s perspective, the proposed enhancements for assisting the network with dynamic waveform switching can be classified in two high-level approaches.

First approach (“Pre-switch assistance”) aims at providing information to the network to help determine whether a change of waveform would be beneficial. The minimum enhancement to support this approach is the reporting of power headroom information applicable to a reference PUSCH using a target waveform different from waveform or actual PUSCH. Additional enhancements for the triggering of PUSCH are also possible, but not all companies think these are necessary.

* Based on contributions, 16 companies are supportive of this approach while 5 companies are not supportive, and 1 company thinks that it should be justified by quantified performance gains.

Second approach (“Post-switch assistance”) aims at providing information to the network about the power headroom situation after the switch so that scheduling adjustments can be made (or perhaps reversion to the earlier waveform). The minimum enhancement to support this approach is a new trigger of power headroom information linked to a waveform switching event.

* Based on contributions, 7 companies are supportive of (or open to) this approach while 3 companies think no new trigger is needed.

As a first step, to further clarify situation, moderator would like to ask companies the following about the above high-level approaches.

### 1st round

Please indicate if your company position was incorrectly captured or if you would like to add your company position to the summary above. Please provide answers to the following questions.

Q1: Which of the two approaches do you think is most useful to support DWS? Are both useful?

Q2: If preferred approach is pre-switch assistance, is it acceptable to support only post-switch assistance? If preferred approach is post-switch assistance, is it acceptable to support only pre-switch assistance?

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# Topic #4: RRC parameters

## [MP][Open] Issue #4-1: Configuration of DWS

**Summary of company views from contributions submitted to RAN1#112bis-e**

Several companies (ZTE [7], InterDigital [12], Panasonic [14], Lenovo [16], Samsung [17], ETRI [18], LG [29]) discuss RRC configuration to enable dynamic waveform switching functionality.

All the above companies identify the need for configuring by RRC whether dynamic waveform switching is enabled. However, several issues still need to be discussed.

Configurability level

Two companies [12][18] propose that dynamic waveform switching is configurable per BWP. One company [16] proposes that parameters applicable to both waveforms are configured within one PUSCH-Config, which implies configurability per BWP. At the beginning of RAN1#112, moderator also asked this question to companies and majority of companies were preferring per-BWP. From moderator’s perspective, configurability per BWP seems natural since parameter *transformPrecoder* which controls the waveform for dynamic grant in R17 is under *PUSCH-Config* which is configured by BWP.

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| **FL proposal 4-1**: Dynamic waveform switching is configured separately for each BWP, within *PUSCH-Config*. |

Two companies [12][16] propose that presence of the 1-bit dynamic waveform switching indication can be configured separately for DCI format 0\_1 and DCI format 0\_2. Other companies [7][14][17][29] discussing RRC enabling/disabling the indication do not discuss this aspect. Some additional discussion may be needed on this.

For the RRC indication, options include (1) additional value to *transformPrecoding* parameter indicating dynamic switching [14][17] or (2) additional RRC parameter indicating if dynamic switching is enabled or disabled [7][14][29]. Both options can be further studied.

One company [16] proposes that parameters for CP-OFDM and DFT-S-OFDM are included under a same PUSCH-Config parameter instead of separate PUSCH-Config parameters. In moderator’s understanding, parameters for both waveforms are already included within PUSCH-Config. In case some parameter for one waveform or the other is missing, it seems reasonable to continue with the same approach.

### 1st round

Please indicate if your company position was incorrectly captured or if you would like to add your company position to the summary above. Please indicate:

* If FL proposal 4-1 is agreeable
* If you think presence of dynamic waveform switching indication can be configured separately for DCI format 0\_1 and 0\_2.

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# References

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| --- | --- | --- | --- |
| 1 | RP-221858 | Revised WID on Further NR coverage enhancements | China Telecom |
| 2 | R1-2302352 | Discussion on dynamic waveform switching for coverage enhancement | Huawei, HiSilicon |
| 3 | R1-2302511 | Discussions on remaining issues of dynamic waveform switching | vivo |
| 4 | R1-2302575 | Considerations on dynamic switching between DFT-S-OFDM and CP-OFDM | OPPO |
| 5 | R1-2302625 | Discussion on dynamic switching between DFT-S-OFDM and CP-OFDM | Spreadtrum Communications |
| 6 | R1-2302692 | Dynamic switching between DFT-S-OFDM and CP-OFDM | CATT |
| 7 | R1-2302761 | Discussion on dynamic waveform switching | ZTE |
| 8 | R1-2302788 | Dynamic switching between DFT-S-OFDM and CP-OFDM waveform | Intel Corporation |
| 9 | R1-2302865 | Considerations on dynamic waveform switching for various PUSCH types | Sony |
| 10 | R1-2302882 | Dynamic switching between DFT-s-OFDM and CP-OFDM | Nokia, Nokia Shanghai Bell |
| 11 | R1-2302972 | Discussion on dynamic switching between DFT-s-OFDM and CP-OFDM | Xiaomi |
| 12 | R1-2303018 | Dynamic switching between DFT-S-OFDM and CP-OFDM | InterDigital, Inc. |
| 13 | R1-2303036 | Discussion on dynamic waveform switching between DFT-s-OFDM and CP-OFDM | China Telecom |
| 14 | R1-2303039 | Discussion on dynamic waveform switching | Panasonic |
| 15 | R1-2303085 | Discussion on solutions for NR dynamic switching between DFT-S-OFDM and CP-OFDM | Mavenir |
| 16 | R1-2303092 | Discussion on dynamic switching between DFT-S-OFDM and CP-OFDM | Lenovo |
| 17 | R1-2303155 | Dynamic switching between DFT-S-OFDM and CP-OFDM | Samsung |
| 18 | R1-2303207 | Dynamic switching between DFT-S-OFDM and CP-OFDM | ETRI |
| 19 | R1-2303258 | Discussion on dynamic switching between DFT-S-OFDM and CP-OFDM | CMCC |
| 20 | R1-2303355 | Dynamic switching between waveforms | MediaTek Inc. |
| 21 | R1-2303382 | Discussion of dynamic switching between DFT-S-OFDM and CP-OFDM | Transsion Holdings |
| 22 | R1-2303510 | Discussion on dynamic switching between DFT-S-OFDM and CP-OFDM | Apple |
| 23 | R1-2303617 | Dynamic switching between DFT-S-OFDM and CP-OFDM | Qualcomm Incorporated |
| 24 | R1-2303641 | Dynamic switching between DFT-S-OFDM and CP-OFDM for Rel-18 CovEnh | Sharp |
| 25 | R1-2303644 | Discussion on dynamic switching between DFT-S-OFDM and CP-OFDM | Google Inc. |
| 26 | R1-2303663 | Discussion on Dynamic UL Waveform Switching | Ericsson |
| 27 | R1-2303682 | Discussion on dynamic switching between DFT-S-OFDM and CP-OFDM | NEC |
| 28 | R1-2303733 | Discussion on dynamic switching between DFT-S-OFDM and CP-OFDM | NTT DOCOMO, INC. |
| 29 | R1-2303752 | Discussion on dynamic waveform switching for NR coverage enhancement | LG Electronics |
| 30 | R1-2302222 | Summary #4 on dynamic switching between DFT-S-OFDM and CP-OFDM | Moderator (InterDigital) |

# Appendix: Previous agreements

RAN1#112

Agreement

For single TB scheduled by single DCI, support new 1-bit field for dynamic waveform indication from UL scheduling DCI.

Note: no change of the current size alignment procedure between UL DCI and DL DCI.

Conclusion

There is no consensus to support “Dynamic waveform switching to PUSCH transmissions with a Type 2 configured grant” in R18.

Agreement

Dynamic waveform switching in R18 is not applicable to PUSCH transmissions with a Type 1 configured grant.

Conclusion

The dynamic waveform indication in a DCI containing a dynamic uplink grant applies only to PUSCH transmission(s) corresponding to the dynamic uplink grant.

RAN1#111

**Agreement**

**For DCI based solution,**

* For supported dynamically scheduled PUSCH, support dynamic waveform switching indication from UL scheduling DCI

Note: “Supported dynamically scheduled PUSCH” is to be confirmed in further discussion

Note: It does not imply that the waveform switching indication applies to other transmission or not

* Indication from non-UL scheduling DCI is not supported.

Note: the working assumption made in RAN1#110b-e for “Support at least one of the following options for the dynamic waveform indication in R18” does not need to be confirmed

Working Assumption

Support new 1-bit field for dynamic waveform indication from UL scheduling DCI

* Note: no change of the current size alignment procedure between UL DCI and DL DCI

Agreement

Study the necessity of the following potential enhancements to assist the scheduler in determining waveform switching:

* Reporting power headroom related information based on PCMAX,f,c applicable to a target waveform
  + Target waveform can be same or different from waveform of an actual PUSCH transmission
  + FFS target RB allocation and/or target modulation order can be same or different from respective properties of an actual PUSCH transmission
  + FFS determination of target waveform, target RB allocation, target modulation order
  + FFS details, e.g. report PCMAX,f,c or Type 1 power headroom for a waveform, or difference thereof between waveforms
* PHR triggering enhancements, e.g.
  + Network-triggered PHR
  + PH becomes lower (higher) than a threshold
  + PHR triggered by waveform switching
* Reporting of recommended waveform or request to switch waveform
* Other solutions not precluded

RAN1#110bis-e

Agreement

Dynamic waveform switching enhancement in R18 is only applicable to PUSCH channel.

**Working Assumption**

Support at least one of the following options for the dynamic waveform indication in R18:

Alt 1: Indication from an UL scheduling DCI

* Alt 1-A: New field in scheduling DCI
* Alt 1-B: Reuse existing field in scheduling DCI
  + Alt 1-B-1: Explicit indication by repurposing field, e.g.
    - Add one column to TDRA table
    - Add one column to MCS table(s)
    - Other solutions not precluded
  + Alt 1-B-2: Implicit determination from condition(s) on scheduling information, e.g.
    - RA type, MSB of RA
    - Number of RBs (below threshold or multiple of 2,3,5)
    - Location of RB allocation within carrier and the associated MPR
    - MCS below threshold
    - Number of PUSCH repetitions (or whether PUSCH repetition is used) and/or TBoMS
    - Number of DMRS CDM group(s) without data
    - Precoding information and number of layers
    - SRI
    - Condition over multiple types of scheduling information
    - Other types of scheduling information not precluded
* Indicated waveform applies at least to the scheduled PUSCH transmission
  + FFS: Whether it also applies to subsequent transmissions, and of which type
* FFS: DCI formats can contain the indication
* FFS: Indication applies only if condition(s) are satisfied (e.g. PDCCH occasion, /RNTI, /Search space of the scheduling DCI, latest PHR reported by the UE, etc.)

Alt 2: Indication from a non-UL scheduling DCI

* FFS: DCI formats that can provide the indication (e.g. Downlink DCI, UE-group common DCI)
* FFS: Types of subsequent transmissions to which indication is applicable

**Agreement**

To study and if necessary, specify, enhancements to assist the scheduler in determining waveform switching, such as:

* Reporting power headroom related information
* Other solutions are not precluded

**Agreement**

Dynamic waveform switching enhancement in R18 is applicable to PUSCH scheduled by DCI format 0\_1 or 0\_2 in PDCCH with CRC scrambled with C-RNTI, MCS-C-RNTI, or CS-RNTI with NDI=1.

* Note: The above does not imply that dynamic switching enhancement in R18 is applicable or not applicable to other cases of PUSCH (e.g. PUSCH transmission with a Type 1 or Type 2 configured grant, PUSCH scheduled by DCI format 0\_0).

R1-2210749 Summary #4 on dynamic switching between DFT-S-OFDM and CP-OFDM Moderator (InterDigital, Inc.)