**3GPP TSG RAN WG1#104-e R1-2xxxxxx**

**e-Meeting, January 25th – February 5th, 2021**

**Agenda Item: 8.2.2**

**Source: Moderator (Lenovo)**

**Title: [Draft] Feature lead summary for [104-e-NR-52-71GHz-02] Email discussion/approval on PDCCH monitoring enhancements**

**Document for: Discussion, Decision**

# Introduction

Among other items, the WID "Extending current NR operation to 71 GHz" includes the following RAN1 objective:

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| Support enhancement to PDCCH monitoring, including blind detection/CCE budget, and multi-slot span monitoring, potential limitation to UE PDCCH configuration and capability related to PDCCH monitoring. |

This document covers the following as announced by the chairman:

[104-e-NR-52-71GHz-02] Email discussion/approval on PDCCH monitoring enhancements with checkpoints for agreements on **Jan-28, Feb-02, Feb-05** – Alex (Lenovo)

Depending on the progress, new questions or proposal may be added after the defined checkpoints.

# Discussion

## First Round Discussion

FL NOTE: Please refer to the documents listed in Section 3 for individual questions for an identified topic.

### Topic A1: Blind Decoding Capability, Multi-slot span monitoring

**Question A1-1a: Do you see a need to support single-slot span monitoring for one or both new numerologies (480 kHz, 960 kHz)?**

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| **Company** | **Comment** |
| Xiaomi | Currently, we see no need. For SCS120khz, the single slot capability is BD/CCE=(20/32). Start from this, for SCS=480/960khz, BD/CCE would be at the level of 10 or even less. Such restriction would cause high blocking probability for even just a few DCIs |
| Qualcomm | For the new SCSs, we think single-slot based PDCCH monitoring should be supported, as well as a new multi-slot based PDCCH monitoring. Although the number of BD/CCE shall be strictly limited for single-slot monitoring, we see there are use cases that more frequent PDCCH monitoring is required, such as an extremely low-latency traffic or outside of a COT. |
| Futurewei | We do not see a strong reason for single slot monitoring at higher numerologies. |
| OPPO | Yes. Single-slot span monitoring is beneficial for some latency-urgent services. |

**Question A1-1b: If yes for Question A1-1a, what are your thoughts on the maximum number of monitored PDCCH candidates and on the maximum number of non-overlapped CCEs for the new numerologies (480 kHz, 960 kHz) in a single-slot span?**

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| **Company** | **Comment** |
| Qualcomm | We think a simple projection (e.g., based on log-linear regression) could be the starting point. Since it is a complicated matter involving lots of implementation and performance aspects (e.g., processing complexity, support for high AL, etc.), further studies should be conducted before making a conclusion.  |

**Question A1-2a: Do you see a need to support new multi-slot span monitoring for the existing SCS of 120 kHz? Or can we conclude that for 120 kHz SCS, no PDCCH monitoring enhancement is needed?**

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| **Company** | **Comment** |
| Xiaomi | Yes. If time allows, it is better to define multi-slot span monitoring for 120kHz SCS, with the same framework as 480/960khz SCS. But multi-slot span monitoring discussion for 480/960khz SCS should be prioritized over 120kHz SCS. |
| Qualcomm | We don’t see strong motivation for this. At least for PDCCH monitoring, we think the existing FR2 designs and capabilities can be reused. |
| Futurewei | We prefer single slot monitoring for PDCCH @ 120 kHz SCS i.e. no PDCCH monitoring enhancement is necessary. |
| OPPO | We think new multi-slot span monitoring is not needed for 120 kHz. But coverage enhancement for 120kHz SCS may be studied. |

**Question A1-2b: In case of multi-slot monitoring, what are your views on monitoring periodicities and the corresponding number and location of OFDM symbols (for 120/480/960 kHz), including a potential duration of more than 3 OFDM symbols?? If convenient, refer to or suggest modifications to the following cases:**

* Case 1: PDCCH monitoring of all SS sets monitored in a slot occurs within 3 consecutive OFDM symbols that have fixed positions in each slot
	+ Case 1-1: PDCCH monitoring limited to within first three OFDM symbols of a slot
	+ Case 1-2: PDCCH monitoring on any span of up to 3 consecutive OFDM symbols of a slot
		- For a given UE, all search space configurations are within the same span of 3 consecutive OFDM symbols in the slot
* Case 2: PDCCH monitoring cases other than Case 1

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| **Company** | **Comment** |
| Xiaomi  | From our view, the first step is to define the monitoring cases within a span, then we go to monitoring cases within a slot. For example, the first step discussion can start from,* Case 1: PDCCH monitoring of all SS sets monitored in a span occurs within N consecutive slotsthat have fixed positions in each slot
	+ Case 1-1: PDCCH monitoring limited to within first N slots of a monitoring span
	+ Case 1-2: PDCCH monitoring on any span of up to N consecutive slots of a monitoring span
		- For a given UE, all search space configurations are within the same span of N consecutive slots in the monitoring span
* Case 2: PDCCH monitoring cases other than Case 1

the second step discussion can start from the original proposal,* Case 1: PDCCH monitoring of all SS sets monitored in a slot occurs within 3 consecutive OFDM symbols that have fixed positions in each slot
	+ Case 1-1: PDCCH monitoring limited to within first three OFDM symbols of a slot
	+ Case 1-2: PDCCH monitoring on any span of up to 3 consecutive OFDM symbols of a slot
		- For a given UE, all search space configurations are within the same span of 3 consecutive OFDM symbols in the slot
* Case 2: PDCCH monitoring cases other than Case 1

We are open to define a potential duration of more than 3 OFDM symbols, since with more symbols configured in a slot for PDCCH, the number of slots need to be monitored for PDCCH in a span is reduced. And it is potentially benefit for power saving since UE can stop monitoring after receiving all the PDCCH within a span. |
| Qualcomm | To support multi-slot based PDCCH monitoring for the new SCSs, we think the separation between two monitoring occasions is a more important factor than the position of PDCCH monitoring occasion within a slot. To provide enough processing time for a reasonable number of BD/CCEs, the separation should be large enough, e.g., multiple slots. Thus, none of Rel-15 and Rel-16 PDCCH monitoring capabilities, such as *pdcch-MonitoringAnyOccasionsWithSpanGap* and *pdcch-Monitoring-r16*, is provisioning enough separation between PDCCH monitoring spans and, therefore, a new capability may need to be introduced. In our view, the Rel-16 capability (*pdcch-Monitoring-r16*) can be the baseline to define the new capability. Proper minimum separation between two MOs may be discussed first, for example 4 slots for 480kHz and 8 slots for 960kHz. Then, it may be further discussed whether the distinction between a “fixed position” (Case 1) or “any position” (Case 2) of MO in the slot is necessary with the new capability. |
| Futurewei | Support Case 1, Case 1-2 PDCCH monitoring of any span up to three consecutive OFDM symbols of a slot. |
| OPPO | We prefer PDCCH monitoring with a maximum duration of more than 3 OFDM symbols per PDCCH monitoring occasion in order to carry more PDCCH candidates. Proposed modification on Case 2:* Case 2: PDCCH monitoring cases other than Case 1
	+ Case 2-1: PDCCH monitoring up to X consecutive OFDM symbols, where X is more than 3
		- FFS: the value of X
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**Question A1-2c: How long should the multi-slot span be, i.e. how many slots (for 120/480/960 kHz)? Several companies seem to support 4 slots for 480 kHz and 8 slots for 960 kHz, are those agreeable?**

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| **Company** | **Comment** |
| Xiaomi | Yes, 4 slots for 480 kHz and 8 slots for 960 kHz can be supported. But we are open to discuss other designs. |
| Qualcomm | For the minimum separation (i.e., gap) between two MOs, 4 slots for 480kHz and 8 slots for 960kHz are agreeable. In addition, based on the UE capability, more than one value for a new SCS may be supported, e.g., {2, 4} slots for 480kHz and {4, 8} slots for 960kHz. |
| Futurewei | We are OK with 4 for 480kHz and respectively 8 slots for 960kHz. |
| OPPO | We think the determination of the maximum multi-slot span depends on how many PDSCHs/PUSCHs can be scheduled with a single DCI. |

**Question A1-2d: For multi-slot span monitoring, what should the basis for defining the PDCCH monitoring capability is based on how to define the PDCCH monitoring capability (e.g. fixed pattern of N slots; flexible pattern; floating/sliding window)?**

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| **Company** | **Comment** |
| Xiaomi | Fixed pattern of N slots should be the basis for define multi-slot PDCCH monitoring capability. Just like in R15 single-slot PDCCH monitoring capability definition, the boundary for a slot is fixed.In fact, we don’t see the need of flexible pattern or floating/sliding window, since it complicate the monitoring cases, which means extra time budget/workload, and brings no clear benefit. |
| Qualcomm | As we commented in Question A1-2b, we think the Rel-16 span-based PDCCH capability (*pdcch-Monitoring-r16*) can be the baseline. A longer separation between two spans (e.g., 4 slot separation for 480kHz and 8 slot separation for 960kHz) can be considered. |
| Futurewei | We prefer a fixed pattern of N slots (TBD) |

**Question A1-3: Is the following proposal agreeable?**

**Cross-carrier scheduling of cell with 52.6-71GHz frequency from/to a cell of FR1 and FR2 is allowed by specification, however, additional enhancements are deprioritized unless a clear motivation is identified.**

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| **Company** | **Comment** |
| Xiaomi  | Support the moderator’s proposal.  |
| Qualcomm | At least the timeline discussion for the new SCSs (i.e., cross-carrier PDSCH and aperiodic CSI-RS preparation time) should not be deprioritized. However, any new procedures specific for the new SCSs would be unnecessary and deprioritized. |
| Futurewei | We support moderator’s proposal. |
| OPPO | We support moderator’s proposal. |

### Topic A2: PDCCH Extensions for e.g. Coverage, Reliability

**Question A2-1: Do you see a need to improve coverage or reliability of PDCCH compared to Rel-15/16? Please provide a motivation.**

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| **Company** | **Comment** |
| Xiaomi | Currently, we don’t see the need but open to discuss it. |
| Qualcomm | As it was already decided in the WID not to pursue the SSB coverage enhancement in Rel-17, we think PDCCH coverage enhancement should also be deprioritized. It may be considered in the future releases. |
| Futurewei | We expect UL coverage limitation therefore we do not see a need to increase the DL coverage. Additional mechanisms such as beamforming will do the job. The usage of lower SCS (120kHz) also will provide enough coverage. |
| OPPO | If time permits, in spectrum with PSD-limit requirement, the coverage enhancement for PDCCH with 120kHz may be investigated.  |

### Topic B: Multiple PDSCH/PUSCH by a single DCI

**FL NOTE: Decisions on BD limitations/capabilities for potential new DCI formats should come after corresponding decisions on support of such scheduling in AI 8.2.5.**

**Question B-1: Do you see a need for PDCCH monitoring restriction in terms of SS configuration with specific DCI formats?**

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| **Company** | **Comment** |
| Xiaomi  | We are not clear about this question. What kind of PDCCH monitoring restrictions? And which specific DCI formats? |
| Qualcomm | Any restriction on the PDCCH monitoring configuration (e.g., periodicity, AL, number of candidates, etc.) should be up to network, as long as it fulfills UE’s PDCCH monitoring capability. |
| Futurewei | Agree with Xiaomi. The question needs further clarifications. |
| OPPO | We should further investigate this issue. |

### Topic C: Multi-Beam Aspects

**Question C-1: Do you have any views on the need for enhancing PDCCH w.r.t. multiple beams?**

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| **Company** | **Comment** |
| Xiaomi  | We are open to discuss. Currently only a few companies have mentioned this topic. Maybe we can wait for more input and discuss later. |
| Qualcomm | PDCCH enhancement associated with multi-beam transmission is already under discussion in eMIMO WI. We don’t think separate discussion is necessary. |
| Futurewei | This discussion may be deprioritized for later. |
| OPPO | We are open for PDCCH enhancement including supporting multiple beams |

### Topic D: Cross-carrier scheduling

**Question D-1: Would you like to provide any views on the documents and proposals listed under Topic D?**

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| **Company** | **Comment** |
| Qualcomm | As we commented in Question A1-3, the preparation time for cross-carrier PDSCH and aperiodic CSI-RS/SRS, should be discussed. Unlike other processing timeline issues for PDSCH/PUSCH, which will be discussed in sub-agenda 8.2.5, the cross-carrier preparation time has implications with PDCCH processing time. Therefore, it should be discussed in this sub-agenda. |
| Futurewei | Support reuse of the existing cross-carrier scheduling specs. Further enhancement may not be necessary. |

### Topic E: Other

**Question E-1: Would you like to provide any views on the documents and proposals listed under Topic E?**

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| **Company** | **Comment** |
| Xiaomi | For our proposals below, we consider they are necessary, and need to discussed for the new SCS 480/960khz. Search space set group switching is introduced in R16 NR-U for power saving propose and group switching time $P\_{switch}$ is defined for SCS 15-60kHz. To facilitate unlicensed band operation for NR 52.6-71GHz, group switching time $P\_{switch}$ should also be defined for 120/480/960kHz ***Proposal 6: Search space set group switching time*** $P\_{switch}$ ***should be defined for 120/480/960kHz.***The maximum search space periodicity in current spec is 2560 slots, and with SCS increased to 960kHz, the absolute time of the maximum search space periodicity will be decreased by 8 times. So new periodicity parameters may need to be introduced for the new SCSs, as well as the search space offset/duration parameters.***Proposal 7:*** ***New search space periodicity parameters, as well as the search space offset/duration parameters, may need to be introduced for the new SCSs.*** |

# Contribution Details

The following sections show extracted discussion and proposals from the contributions submitted to this AI.

## Topic A1: Blind Decoding Capability, Multi-slot span monitoring

List of issues, proposals, and suggestions for handling in the email discussion phase.

### R1-2100058 (Lenovo, Motorola Mobility)

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| In RAN1#103-e and in the WID, it has been agreed to specify enhancements to schedule multiple PDSCH/PUSCH by a single DCI. One of the main motivations for this is to avoid the need for UE to monitor PDCCH scheduling PDSCH/PUSCH in every slot as it may not be feasible to monitor and decode by UE due to very short slot duration for higher SCS values such as 480kHz and 960kHz. Therefore, it is quite straightforward extension to allow the possibility for a UE to be configured with multi-slot PDCCH monitoring span, where the UE is not required to monitor PDCCH in every slot.***Proposal 1: For supporting NR between 52.6 GHz and 71 GHz with high subcarrier spacing values including 480kHz and 960kHz, multi-slot PDCCH monitoring span should be supported.***Furthermore, exact duration of the multi-slot PDCCH monitoring span can be configurable with different values in terms of number of slots depending upon the SCS values. For example, with 480kHz SCS value, multi-slot PDCCH monitoring span is 4 slots and with 960kHz SCS value, multi-slot PDCCH monitoring span is 8 slots. ***Proposal 2: For supporting NR between 52.6 GHz and 71 GHz with high subcarrier spacing values including 480kHz and 960kHz, if multi-slot PDCCH monitoring span should be supported, then the exact duration of the span can be configured depending upon the subcarrier spacing value.***With high SCS values, the absolute duration of the slot is greatly reduced and moreover, when single DCI can schedule multi-PDSCH/PUSCH over multiple slots, it might be beneficial to consider longer duration than 3 symbols for CORESETs. Multiple benefits can be associated with longer duration:* Better support for higher aggregation levels for better reliability
* More resources available for CORESET, but with same or even reduced duration in absolute time
* More symbols available to allow TDM multiplexing between DM-RS and control information
	+ Benefit of a DM-RS symbol with continuous frequency resources will account for better channel estimation with higher SCS values.

In fact, for very high SCS value such as 960kHz, even an entire slot for PDCCH can be considered to allow for only single PDCCH monitoring occasion within a slot.***Proposal 5: For supporting NR between 52.6 GHz and 71 GHz with high subcarrier spacing values including 480kHz and 960kHz, CORESET duration longer than 3 symbols should be supported:**** ***FFS: Maximum duration up to 14 symbols in a slot.***
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### R1-2100074 (ZTE, Sanechips)

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| **Observation 1: For supporting NR operation in 52.6 GHz ~ 71 GHz with SCS 480 kHz & 960 kHz, the PDCCH monitoring capability will be further relaxed, the maximum number of non-overlapped CCEs and PDCCH candidates per slot could be further limited, and the use of the highest CCE aggregation level may be affected.****Option 1:** Define PDCCH BD capability based on a reference period. For example, define PDCCH BD capability according to a slot length of a reference SCS 120 kHz. When configuring the search space set by higher layer parameter *monitoringSlotPeriodicityAndOffset*, the gNB needs to ensure that the duration *TS* is an integral multiple of the slot length of 120 kHz SCS.**Option 2:** Define PDCCH BD capability based on a slot group and PDCCH monitoring is performed on multiple slots. When configuring the search space set by higher layer parameter *monitoringSlotPeriodicityAndOffset*, the gNB needs to ensure that the duration *TS* is a multiple of n slots (n equals to the number of slots contained in the slot group), or a multiple of slot groups in the basic unit of slot group. For example, if a slot group includes four slots, the duration *TS* can be configured as 4, 8, 12, 16, ... of slots. Alternatively, the duration *TS* can be configured as 1, 2, 3, 4, ... of slot groups, i.e. the basic granularity of the duration *TS* should be defined as a slot group. Figure 1 gives two configuration types in a slot group for Option 2.(a) Configuration 1 in Option 2(b) Configuration 2 in Option 2**Figure 1: Define PDCCH BD capability based on a slot group in Option 2****Option 3:** Reduce the monitoring frequency by limiting the configuration of CORESET and/or search space set, such as configuring a larger PDCCH monitoring periodicity *KS* and a smaller PDCCH detection duration, e.g. *TS* = 1. Option 3 can be considered as an implementation issue, i.e. left to gNB configuration.However, Option 3 obviously limits the scheduling flexibility and also may lead to PDCCH congestion. Therefore, a better way is the combination of Option 3 and **Option 4** that can schedule multiple PDSCH/PUSCH via a single DCI. Multiple PDSCH/PUSCH scheduling with a single DCI can not only save DCI overhead, but also reduce PDCCH monitoring frequency without sacrificing scheduling flexibility.In addition to the combination of Option 3 and Option 4, other options can also be combined to enhance PDCCH monitoring, such as Option 1 and Option 4, Option 2 and Option 4, etc.**Proposal 1: The following options can be considered to enhance PDCCH monitoring for NR operation in 52.6 GHz ~ 71 GHz with the newly introduced SCS i.e. 480 kHz & 960 kHz:*** **Option 1: Define PDCCH BD capability based on a reference period**
* **Option 2: Define PDCCH BD capability based on a slot group**
* **Option 3: Reduce PDCCH monitoring frequency by limiting the configuration of CORESET and/or search space set**
* **Option 4: Schedule multiple PDSCH/PUSCH with a single DCI**
* **Option 5: The combination of two or more options from the above**
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### R1-2100150 (OPPO)

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| With the introduction of 480kHz and 960kHz for data and control transmission, the capabilities for PDCCH monitoring should be reduced. For simplicity, we use the capability for combination (2, 2) as the reference, and by scaling the numbers we can roughly calculate the blind detection/CCE budget for PDCCH monitoring with higher SCSs. Table 1 and Table 2 show the examples of the scaled values for PDCCH monitoring with 480kHz and 960kHz for PDCCH candidates and CCE budgets respectively. Here we considered PDCCH monitoring per slot, per 2-slot, per 4-slot and per 8-slot.**Table 1: Maximum number of monitored PDCCH candidates**

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|  | **Maximum number** $M\_{PDCCH}^{max,\left(X,Y\right),μ}$ **of monitored PDCCH candidates per serving cell**  |
| $$μ$$ | Per slot | Per 2-slot | Per 4-slot | Per 8-slot |
| 5 | 6 | 12 | 24 | 48 |
| 6 | 3 | 6 | 12 | 24 |

**Table 2: Maximum number of non-overlapped CCEs**

|  |  |
| --- | --- |
|  | **Maximum number** $C\_{PDCCH}^{max,\left(X,Y\right),μ}$ **of non-overlapped CCEs per serving cell** |
| $$μ$$ | Per slot | Per 2-slot | Per 4-slot | Per 8-slot |
| 5 | 6 | 12 | 18 | 36 |
| 6 | 6 | 12 | 18 | 36 |

**Proposal 1: The maximum number of monitored PDCCH candidates and the maximum number of non-overlapped CCEs can be roughly calculated from the PDCCH monitoring capability of combination (2, 2).**As discussed above, with the introduction of 480kHz and 960kHz for data and control transmission in the high frequency range, compared to existing SCS, the symbols become much shorter and the frequency range will be much larger for a given CORESET configuration. Figure 1 compares the CORESET configuration of {12RBs, 2symbols} for 120kHz and 480kHz respectively. **Figure 1: CORESET configuration of {12RBs, 2symbols} for 120kHz and 480kHz**From Figure 1, it can be observed that to keep same CORESET configurations and same PDCCH candidates being monitored, compared to 120kHz SCS, the coverage of PDCCH transmission would be impacted due to the reduced transmission duration, and UE is required to estimate much higher frequency range with the SCS of 480kHz. While the maximum number of non-overlapped CCEs would be smaller for 480kHz SCS than 120kHz SCS. The difference would be much larger if 120kHz and 960kHz SCSs are compared. Therefore, enhancements to CORESET configuration, i.e., reducing CORESET RBs and increasing CORESET symbols for a given higher SCS, seem beneficial. **Proposal 2: CORESET configuration with less RBs and more symbols for 480kHz and 960kHz SCS should be supported.** |

### R1-2100241 (Huawei, HiSilicon)

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| ***Observation 1****: Further reducing the slot-level PDCCH monitoring capabilities for 480/960 kHz SCSs will cause the numbers of PDCCH candidates and non-overlapped CCEs to become too small, which may result in lower achievable aggregation levels.*To solve the issue, multi-slot span monitoring can be introduced, i.e., extending the PDCCH monitoring unit from slot to multi-slot. To specify the multi-slot span monitoring, we investigate the following aspects:* + Monitoring capabilities
	+ Search space set

First, the monitoring capabilities can be defined over multiple slots, i.e. the monitoring unit is defined as X slots where X > 1. To save specification efforts, we suggest to support a common span for all SCSs supported above 52.6 GHz. A simple way is to align the span with one slot of 120 kHz SCS, i.e., for 480 kHz SCS, a PDCCH monitoring span can contain four slots, and for 960 kHz SCS, a PDCCH monitoring span can contain eight slots.***Proposal 1****: Introduce the following PDCCH monitoring span for PDCCH monitoring, where the maximum number of monitored PDCCH candidatesfor a DL BWP for a single serving cell is defined over a PDCCH monitoring span, and the maximum number of non-overlapped CCEsfor a DL BWP for a single serving cell is defined over a PDCCH monitoring span, for SCS configurations of 480 and 960 kHz:** + *for 480 kHz SCS, a PDCCH monitoring span contains four slots*
	+ *for 960 kHz SCS, a PDCCH monitoring span contains eight slots*

***Proposal 2:*** *The time domain parameters of search space set configuration should be enhanced to adapt to the multi-slot span monitoring by** + *adding new periodicities to increase the flexibility of search space set configuration*
	+ *changing the unit of duration to multi-slot span*

In Rel-15, the following PDCCH monitoring cases are defined:* Case 1: PDCCH monitoring periodicity of 14 or more symbols
	+ Case 1-1: PDCCH monitoring on up to three OFDM symbols at the beginning of a slot
	+ Case 1-2: PDCCH monitoring on any span of up to 3 consecutive OFDM symbols of a slot
* Case 2: PDCCH monitoring periodicity of less than 14 symbols

If multi-slot span monitoring is adopted, the current definition of the cases may not be able to be applied to 480 kHz/960 kHz SCS directly. Therefore, to facilitate further discussion, RAN1 should clarify the monitoring cases under the assumption of multi-slot monitoring. The following definition can be a starting point for further discussion:* Case 1: PDCCH monitoring periodicity of 14\*X or more symbols
	+ Case 1-1: PDCCH monitoring on up to three OFDM symbols at the beginning of a multi-slot span
	+ Case 1-2: PDCCH monitoring on any span of up to 3 consecutive OFDM symbols of a multi-slot span
* Case 2: PDCCH monitoring periodicity of less than 14\*X symbols
* Note: X is the number of slots in a span

In our view, similar to PDCCH monitoring in FR2, Case 1-1 should be the baseline for multi-slot monitoring, and RAN1 should further analyze whether the other cases are necessary or not.***Proposal 3:*** *For multi-slot monitoring in 52.6~71 GHz, RAN1 should clarify the definition of PDCCH monitoring cases, and further study which case(s) should be supported if the PDCCH monitoring periodicity is defined based on a span of 14\*X symbols (instead of 14 symbols).* |

### R1-2100258 (Nokia, Nokia Shanghai Bell)

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| NR Rel-16 supports PDCCH monitoring restriction according to span -based monitoring. It’s defined according to two parameters, X and Y:* X (symbols) is the minimum time separation between the first symbols of two consecutive spans
* Y (symbols) is the maximum duration of the span.

The span -based monitoring defined in Rel-16 supports only scenarios with X≤7. This corresponds to span-based monitoring within a slot. However, the Rel-16 solution scales to multi-slot scenario as well, and it makes sense to define monitoring restriction for 60GHz scenario based on the same operation logic. This means that the number of monitored PDCCH candidates per span, and the number of non-overlapped CCEs needs to be determined not only per slot, but also per combination (X, Y).***Proposal 1:**** *Support both slot-based multi-slot span -based monitoring for 480 kHz and 960 kHz SCSs*
* *All UEs supporting 480 kHz or 960 kHz SCS should support multi-slot span -based monitoring.*

The first question is how to determine values for parameter *X*? Table 1 shows the number of slots and OFDM symbols w.r.t. a slot with 120 kHz SCS. Based on Note2 [2]“*UEs supporting a band in the range of 52.6GHz-71GHz are not required to support 480kHz SCS and 960kHz SCS*”. This means that 120 kHz SCS is supported by all UEs and all 60GHz deployments. * We think that the maximum number of PDCCH candidates and non-overlapping CCEs could be defined in terms of 120 kHz slots. This corresponds to 4 slots with 480 kHz SCS and 8 slots with 960 kHz SCS, respectively.
* Additionally, we think that span of [2] slots should be supported for 480 kHz SCS, and span of [2, 4] slots should be supported for 960 kHz SCS, respectively.

***Proposal 2:*** *Support the following parameters for X** *X=[28, 56] for 480 kHz SCS*
* *X=[28, 56, 112] for 960 kHz SCS.*

Table 1. Number of slots and symbols / 120 kHz slot (~0.125ms)

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| --- | --- | --- |
| SCS (kHz) | # of slots / 0.125ms | #of symbols / 0.125ms |
| 120 | 1 | 14 |
| 480 | 4 | 56 |
| 960 | 8 | 112 |

For parameter Y, the natural starting point is Y=[1, 2, 3] (i.e. the size options currently available for CORESET duration). ***Proposal 3****: Support at least Y=[1, 2, 3] for multi-slot -span monitoring*Table 2 shows an example for defining PDCCH monitoring capabilities. When considering numerical values for the maximum number of PDCCH candidates per span, and the maximum number of non-overlapping CCEs per span, we think that the existing capabilities defined for 120 kHz SCS could be used as a baseline.* 20 PDCCH candidates per 120 kHz slot duration
* 32 non-overlapped CCEs per (120 kHz) slot duration.

In addition to multi-slot span -based monitoring, UEs with 480 kHz and 960 kHz SCSs should support slot-based monitoring. In order to support slot-based operation with reasonable coverage, one should support at least 8 non-overlapped CCEs (preferably 16) also for slot-based operation. There are number of TBDs in Table 2. The numerical values for these should be decided during the WI.***Proposal 5****: Consdier PDCCH monitoring capabilities defined for 120 kHz SCS as a baseline for multi-slot -span based monitoring** *support at least 20 PDCCH candidates per 120 kHz slot duration*
* *support 32 non-overlapped CCEs per 120 kHz slot duration.*
* *support at least 8 non-overlapped CCEs also for slot-based operation.*

Table 2. Example table demonstrating UE capabilities for multi-slot span -monitoring

|  |  |  |
| --- | --- | --- |
|  | Max. # of monitored PDCCH candidates per slot/span per combination (X,Y) and per serving cell | Max. # of non-overlapped CCEs per slot/span for per combination (X,Y) and per serving cell |
| *μ* | Slot-based | (28, Y) | (56, Y) | (112, Y) | Slot based | (28, Y) | (56, Y) | (112, Y) |
| 3 | 20 | - | - | - | 32 | - | - | - |
| 5 | TBD | TBD | ≥20 | - | ≥8 | TBD | ≥32 | - |
| 6 | TBD | TBD | TBD | ≥20 | ≥8 | TBD | TBD | ≥32 |

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### R1-2100371 (CATT)

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| One example of a time span cross multiple slots for 480 and 960 kHz SCS is to define a duration, such as the slot duration 0.125 ms of SCS =120KHz, There are 4 and 8 slots within a 0.125 ms time span for 480 and 960 kHz SCS respectively. The maximum number of monitored PDCCH candidates are increased in proportioned but with ceiling bounded at 44 as shown in Table 1. Table 1: Maximum number $M\_{PDCCH}^{max,slot,μ}$ of monitored PDCCH candidates per time span for a DL BWP with SCS configuration $μ\in \left\{0, 1,2,3,5,6\right\}$ for a single serving cell based on that in Clause 10.1 of TS38.213

|  |  |  |
| --- | --- | --- |
| $$μ$$ | Maximum number of monitored PDCCH candidates per time spant and per serving cell $M\_{PDCCH}^{max,slot,μ}$ | Slot number of a time span |
| 0 | 44 | 1 |
| 1 | 36 | 1 |
| 2 | 22 | 1 |
| 3 | 20 | 1 |
| 5 | **11/44** | **1/4** |
| 6 |  **10/44** | **1/8** |

Table 2: Maximum number $M\_{PDCCH}^{max,\left(X,Y\right),μ}$ of monitored PDCCH candidates in a span for combination (X, Y) for a DL BWP with SCS configuration $μ\in \left\{0, 1\right\}$ for a single serving cell in Clause 10.1 of TS38.213

|  |  |
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|  | Maximum number $M\_{PDCCH}^{max,\left(X,Y\right),μ}$ of monitored PDCCH candidates per span for combination $\left(X,Y\right)$ and per serving cell  |
| $$μ$$ | (2, 2) | (4, 3) | (7, 3) |
| 0 | 14 | 28 | 44 |
| 1 | 12 | 24 | 36 |

**Proposal 1: The maximum number of monitored PDCCH candidates for 480 and 960 kHz SCS could be defined per slot or per time span cross multiple slots (e.g. 4 slot for SCS=480, and 8 slots for SCS=960kKHz). The exact numbers of monitored PDCCH candidates for 480 and 960 kHz SCS are FFS.****Proposal 2: The system/UE complexity and specification impacts should be considered when the maximum number of monitored PDCCH candidates is determined** |

### R1-2100430 (vivo)

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| **Proposal 1: For NR operation from 52.6-71GHz, PDCCH monitoring capability in FR1&FR2 should be relaxed from slot level to multi-slot level granularity.**To support multi-slot level granularity, the most important issue is to define the multi-slot span that PDCCH monitoring capability is based on. There are two alternatives as described below:* Alt. 1: Fixed multi-slot span based on subframe structure
* Alt. 2: Flexible multi-slot span based on SS configuration and subframe structure

**Proposal 2: To support multi-slot level granularity for PDCCH monitoring capability definition, how to determine multi-slot span pattern should be considered, e.g. fixed or flexible multi-slot pattern.**For mandatory capability definition, Alt. 1 is more suitable as the baseline since it is simpler than Alt. 2. For example, UE is required to monitor the first slot of each multi-slot span. Furthermore, the capability for PDCCH monitoring symbols within the slot could reuse that in FR2. Therefore, the following proposal is made for mandatory PDCCH monitoring capability in NR operation from 52.6-71GHz.**Proposal 3: For NR operation from 52.6-71GHz, UE is expected to be mandatory to monitor PDCCH in the first slot of each fixed multi-slot span where the PDCCH monitoring occasions within the slot satisfy the following conditions:*** **The duration of coreset associated with the PDCCH monitoring occasions is 1-3 symbols;**
* **For type 1 CSS with dedicated RRC configuration, type 3 CSS, and USS, the monitoring occasion is within the first 3 OFDM symbols of the slot;**
* **For type 1 CSS without dedicated RRC configuration and for type 0, 0A, and 2 CSS, the monitoring occasion can be any OFDM symbol(s) of the slot, with the monitoring occasions within a single span of three consecutive OFDM symbols within the slot.**

However, Alt. 1 only allows gNB to configure SS in fixed slot position, which is not flexible for gNB configuration from system perspective. Alt. 2 provides a more flexible choice and UE may monitor PDCCH in any slot, which could be an optional capability. **Proposal 4: For NR operation from 52.6-71GHz, flexible multi-slot span pattern could be considered for definition of optional PDCCH monitoring capability.**First, 120KHz SCS is also the supported numerology for NR FR2 operation. The difference on the range of center frequency doesn’t bring any difference on PDCCH monitoring complexity. Therefore, the BD/CCE budget value for 120KHz (i.e. $μ$=3) in FR2 could be reused for that for NR operation from 52.6-71GHz**Proposal 5: For a DL BWP with 120KHz SCS in 52.6-71GHz, UE derives the BD/CCE budget as the same as that for 120KHz in FR2 including the budget value.**Second, 480KHz and 960KHz are new supported numerologies in 52.6-71GHz. Obviously, the BD/CCE budget value should be defined for them taking into UE complexity into account. Namely, the value for $μ$=5 and $μ$=6 should be added into the **Table 1** and **Table 2**. **Proposal 6: For a DL BWP with 480KHz and 960KHz SCS in 52.6-71GHz, the BD/CCE budget value per slot per serving cell should be determined based on practical UE implementation complexity.**Third, the time domain granularity of current BD/CCE budget definition is per slot as observed from Section 2.2.1. However, PDCCH monitoring capability will be based on multi-slot level as proposed in 2.1.2. Naturally, BD/CCE budget per multi-slot span per serving cell should be defined, e.g. proportional to the value per slot per serving cell by the number of slots within a multi-slot span. This could be used for single cell operation directly. In this case, UE is not expected to monitor more than $M\_{PDCCH}^{max,slot-span,μ}$PDCCH candidates with more than $C\_{PDCCH}^{max,slot-span,μ}$ non-overlapped CCEs per slot in the single serving cell.**Proposal 7: For a DL BWP with 480KHz and 960KHz SCS in 52.6-71GHz, the BD/CCE budget value per multi-slot span per serving cell should be defined and it is used for single cell operation scenario.**For multi-cell operation scenario, the situation becomes more complex by introducing such multi-slot span based BD/CCE budget definition. For Case B in NR FR1&FR2 operation, the scheduling cells with the same SCS are categorized together to meet a total limit. However, for one UE operation in both FR1&FR2 and 52.6-71GHz (e.g. CA deployment), BD/CCE budget is applied per slot level in some scheduling cells while per multi-slot span in other scheduling cells. How to category the scheduling cells to be restricted with a total BD/CCE limit needs to be considered taking into account the above hybrid scenario. Particularly, although the SCS and BD/CCE limit granularity in terms of slot number are different for different scheduling cells, the absolute time domain granularity may be the same, e.g. cell A with 120KHz SCS and slot level BD/CCE budget and cell B with 480KHz SCS and BD/CCE budget per 4 slots. **Proposal 8: For multi-cell operation, the categorization of scheduling cells to be applied with a total BD/CCE limit should consider PDCCH SCS and BD/CCE limit granularity jointly.** |

### R1-2100608 (MediaTek)

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| Proposal 1: For 120 kHz SCS, no PDCCH monitoring enhancement is needed. The existing FR2 designs and capabilities for PDCCH monitoring of 120 kHz SCS are reused.For large SCSs (480 kHz and 960kHz), in SI phase, many companies [3][4][5][6] proposed new time units other than per slot or per span for BD/CCE limit, e.g., BD/CCE limits per multi-slot, to address the scaled down per slot BD/CCE limit from shorter slot duration of large SCS configuration and to achieve practical scheduling flexibility with the consideration of Rel-15/16 UE capability. However, BD/CCE limit per new monitoring time unit doesn’t completely address the two UE monitoring complexity issues stated previously without specifying the associated monitoring behavior applied for such BD/CCE limit. For example, without any further configuration restriction, UE can still be configured to monitoring PDCCH in every slots under the capability of BD/CCE limit per multi-slot, which defies the purpose of such enhancement. Moreover, without specifying the PDCCH monitoring configuration applicable for BD/CCE limit of new monitoring time unit, the BD/CCE limit needs to serve for all the possible configuration within the new monitoring time unit, which will complicate the discussion. Therefore, it is necessary to first specify the PDCCH monitoring configurations applied for the new monitoring time unit. With this regard, we propose to limit or at least prioritize the discussion of multi-slot monitoring to the configuration of monitoring PDDCH in the first $n$ slots of every $m$ slots and design the associated new BD/CCE limit accordingly. An example of ($m=4,n=1$) is shown in Figure 1.Figure 1: Proposed multi-slot monitoring framework example of ($m=4,n=1$) Under this framework, UE should signal gNB the supported combination of ($m,n$) as capabilities and the BD/CCE limits for each ($m,n$) combination should be determined. Proposal 2: For 480 and 960 kHz SCSs, multi-slot PDDCH monitoring enhancement should limit the discussion to the configuration of monitoring the first $n$ slots in every $m$ slots. The associated UE capabilities and BD/CCE limits should be defined accordingly. It is worth mentioning the connection between FG 3-5b and the proposed monitoring framework. In Rel-16, a span notion is introduced and defined as a number of consecutive monitoring occasions within a slot where a UE is configured to monitor PDCCH. FG 3-5b describes the possible combination of ($X,Y$) UE can signal as capabilities, where $X$ specifies the minimum symbol gap between the start symbols of every pair of spans and $Y$ specifies the maximum number of symbols within each span. It can be clearly seen that the proposed framework and ($m,n$) definition follows the same spirit of span and ($X,Y$) by modifying the span definition of consecutive symbols to consecutive slots for PDCCH monitoring and modifying the symbol gap $X$ to slot gap $m$. Therefore, similar to FG 3-5b, supported ($m,n$) should be specified as UE PDCCH monitoring capabilities. To design the BD/CCE limit for the combination of ($m,n$), the legacy per slot monitoring should be discussed first, i.e., ($m=1,n=1$). Although per slot monitoring may not be a desirable monitoring mode, it is still useful in some scenarios, e.g., fall-back mode. Moreover, per slot BD/CCE monitoring limit can provide a reference to benefit the discussion of the BD/CCE limit of new time unit. Proposal 3: For 480 and 960 kHz SCS, legacy per slot monitoring should be supported and the associated BD/CCE limit should be defined accordingly.As a consequence of PDCCH monitoring enhancement, another discussed DL enhancement is PDSCH scheduling. In particular, the enhancement of multi-PDSCH scheduled by one DCI has been included in WI to improve data rate under the reduced UE PDCCH monitoring frequency with the help of cross slot scheduling. On the other hand, when the legacy per slot monitoring is configured, same slot scheduling is preferred to maximize the throughput. With the short slot duration of 480 kHz and 960 kHz, it is essential to design a feasible UE behavior of PDCCH monitoring within a slot to realize the same slot scheduling. Therefore, we propose to confine PDCCH monitoring within the first 3 symbols of a slot when per slot monitoring is configured with 480 kHz and 960 kHz SCSs. **Proposal 4: For 480 and 960 kHz SCS, PDCCH monitoring is confined to be within the first 3 symbols of a slot when per slot monitoring is configured.** |

### R1-2100644 (Intel)

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| Specifically, 3 cases for SS set configuration within a slot are supported by parameter *monitoringSymbolsWithinSlot*,* Case 1: PDCCH monitoring of all SS sets monitored in a slot occurs within 3 consecutive OFDM symbols that have fixed positions in each slot
	+ Case 1-1: PDCCH monitoring limited to within first three OFDM symbols of a slot
	+ Case 1-2: PDCCH monitoring on any span of up to 3 consecutive OFDM symbols of a slot
		- For a given UE, all search space configurations are within the same span of 3 consecutive OFDM symbols in the slot
* Case 2: PDCCH monitoring cases other than Case 1

Case 1-1 is the basic PDCCH monitoring occasion(s) in the beginning of a slot, which should be supported for high SCS. Case 2 is to configure more frequent PDCCH MOs within a slot, which is targeted to reduce scheduling latency. This is important especially for low SCS, e.g. 15kHz or 30kHz. On the other hand, it is not necessary for a high SCS, e.g. 480kHz or 960kHz, given that the slot length is quite short, i.e. 1/32ms or 1/64ms. In this case, there is no clear motivation to allow full flexibility on the positions of PDCCH MO(s) in a slot, i.e. Case 2. Therefore, restriction on PDCCH MOs in a slot can simplify UE implementation without performance degradation. **Proposal 1: On the PDCCH monitoring occasion in a slot*** **Case 1-1 is supported for all SCS 120kHz, 480kHz and 960kHz**
* **Case 2 is supported for SCS 120kHz**
* **Case 2 is not supported for SCS 480/960kHz**

With the existing SS set configuration, up to 40 SS sets need to be configured to achieve the MO pattern in Figure 1. On the other hand, considering different DCI formats (fallback DCI or normal DCI) and different type of SS set (USS, CSS type0/0A/1/2, CSS type3 with different DCI formats), the required number of SS sets must be much higher than 40. The main drawback of the current SS set configuration comes from the parameter ‘*duration*’which is defined as a number of consecutive slots.To support the MO pattern for SCS 960kHz in Figure 1, a simple extension is to allocate a MO in every N slot, instead of consecutive slot allocation. The parameter ‘*duration*’ is still needed but can be reinterpreted as the window that MOs may be allocated, e.g. the DL period in a TDD period. Denote the number of slots that are configured with MOs of the USS set as M, then $duration=N∙M$.**Proposal 2: Within a period of a SS set configuration*** **The parameter ‘duration’ is reinterpreted as a window on which MOs may be configured.**
* **One slot in every N slots within the window is configured with PDCCH MOs**

As discussed above, the scope of the WI [1] is to define UE capability on PDCCH monitoring in a large window. It is preferable that the length of the window can be configurable by high layer signalling. The potential values of the window length may depend on the SCS too. For example, the maximum window length may be 8 slots which equal to the slot length with SCS 120kHz. Slot length 1 may be included as a special case. In fact, value 1 is needed to support SCS 120kHz, however, it may be too short for SCS 960kHz. One more discussion point is that whether multi-slot span can be applicable to SCS 120kHz. Finally, there is no motivation to support a concept of URLLC-like span, since it conflicts with basic motivation of the WI, i.e. larger window of max BDs/CCEs for a UE capability. **Proposal 5: Span of 2 or 3 symbols as defined in eURLLC is not supported in 52.6-71GHz frequency****Proposal 6: To support multi-slot span based UE capability on maximum numbers of BDs/CCEs*** **There is no further limitation on maximum numbers of BDs/CCEs in a slot**
* **The number of slots in a multi-slot span can be configured by RRC, potential values 1, 2, 4, 8**
	+ **FFS: Certain value may not be applicable to a SCS**
* **FFS: if multi-slot span can be configured for SCS 120kHz**

**Observation 1: gNB may respectively configure most/all BDs/CCEs in consecutive slot A and B which belong to different multi-slot spans. Such a configuration enforces a larger PDCCH detection capability for UE.** **Proposal 7: It is necessary to pose certain limitation on the BDs/CCEs in two adjacent/consecutive slots that belong to different multi-slot spans.** **Proposal 8: PDCCH overbooking applies per multi-slot span,*** **For PCell or PSCell, it is allowed that the configured number of BDs/CCEs in a multi-slot span by the configuration of SS set(s) is larger than the corresponding maximum numbers. Certain dropping rule is defined so that the actual number in the multi-slot span doesn’t exceed the corresponding maximum numbers.**
* **For a SCell, the gNB should guarantee that the configured numbers of BDs/CCEs in a multi-slot span by the configuration of SS set(s) do not exceed the corresponding maximum numbers.**

**Observation 2: The numbers of BDs/CCEs for CSS sets in the multiple slots of a multi-slot span is increased, which requires higher UE capability on BDs/CCEs to accommodate USS sets.** **Proposal 9: A UE does not expect a CSS set will be dropped in PDCCH overbooking****Proposal 10: To handling USS dropping in PDCCH overbooking** * **A USS set with largest SS set index is dropped**
* **If the PDCCH MOs of a USS set are configured in multiple slots in the multi-slot span, the USS set in all the multiple slots is dropped slot by slot.**
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### R1-2100817 (Spreadtrum)

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| In order to maintain the same UE processing capability as Rel-16, the maximum number of PDCCH BDs per slot will decrease significantly when large SCS is introduced, which affects scheduling flexibility and increases the probability of PDCCH blocking. For the above two problems, we give the following possible solutions. One possible way is to extend the span of PDCCH monitoring to more than one slot for maximum PDCCH BD capability. For example, taking 120kHz as a reference SCS, and the total number of PDCCH BD within 8 slots of 960KHz SCS is limited by the maximum PDCCH BD candidates number defined for 120kHz. In this way, the scheduling and power consumption problems caused by the UE PDCCH monitoring capability can be alleviated. The other alternative is to perform PDCCH blind detection 20 times in a relaxed period. The number of PDCCH BDs can be dynamically allocated according to the PDCCH situation on each slot, or equally allocated. For instance, if relax slots is required to make 20 times PDCCH BDs for 960KHz, the number of PDCCH BD is 2.5 in each slot. ***Observation 1: For NR beyond 52.6 GHz, if larger subcarrier spacings are adopted, the PDCCH monitoring capability and the number of PDCCH candidates per slot would be further reduced.******Observation 2：When a larger subcarrier spacing is introduced in above 52.6GHz frequency range, maximum number of BDs/CCEs for PDCCH monitoring needs to be investigated.*** ***Proposal 1: Defining PDCCH BDs limits over a group of slots or relaxing PDCCH monitoring should be studied for above 52.6GHz.*** |

### R1-2100837 (InterDigital)

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| During RAN study item on requirements for NR beyond 52.6 GHz [2], various benefits of 52.6 – 71 GHz such as high speed data rate, low latency and high capacity have been identified based on the enormous amount of available contiguous bandwidth. Based on the benefits, various use cases for 52.6 – 71 GHz are also envisioned. Among the envisioned use cases, most of the use cases such as short-range high-data rate D2D, vertical industry factory application, IAB, Factory automation/IIoT, AR/VR, ITS/V2X and critical medical communication require low latency as a key requirement. However, if NR only supports multi-slot based PDCCH monitoring for efficient signaling, benefits from low latency possible use cases will be significantly reduced. ***Observation 1:*** *For NR in 52.6 – 71 GHz, most of identified use cases require low latency as a key requirement, however, benefits from low latency and possible use cases significantly reduce if only multi-slot based PDCCH monitoring is supported.* ***Proposal 1:*** *Support both per-slot level monitoring and multi-slot level monitoring for transmission and reception.*In contrast to existing SCS, per-slot level monitoring may lead to a more complex UE implementation considering reduced slot durations and UE processing time. Given that, it is desirable to have multi-slot level monitoring for general UE operations e.g., high data rate eMBB and per-slot level monitoring for UEs which require low latency. ***Observation 2:*** *Per-slot level monitoring requires a more complex UE implementation due to reduced slot durations of additional SCSs and possibly UE processing time.* ***Proposal 2:*** *It is preferred to support multi-slot level monitoring for general UE operations and per-slot level monitoring for low latency operations.****Observation 3:*** *As slot durations for additional SCSs (e.g., 31.3 us for 480 kHz and 15.6 us for 960 kHz) are already short enough, limitation based on a span may not be needed for 52.6 – 71 GHz.**Maximum number of monitored PDCCH candidates/non-overlapped CCEs per span is not needed for NR 52.6 – 71 GHz as high SCSs provide short slot durations and enough low latency.* ***Proposal 3:*** *For the existing limitations, it is preferred to define maximum numbers of PDCCH candidates/non-overlapped CCEs per slot for additional SCSs.*For multi-slot level monitoring, additional limitation should be additionally supported. One possible solution is to extend the existing limitations for Rel-15/16 for monitored PDCCH candidates/non-overlapped CCEs. For example, as UE receives an indication for monitoring capability type e.g., Rel-15 type (per slot) or Rel-16 type (per span) in PDCCH config, another configuration can be additionally supported in PDCCH-config with additional limitation tables as shown in Tables 5 *–* 6.Table 5 Maximum number $M\_{PDCCH}^{max,slot,μ}$ of monitored PDCCH candidates in X slots

|  |  |
| --- | --- |
| $$μ$$ | Maximum number of monitored PDCCH candidates per X slots and per serving cell $M\_{PDCCH}^{max,slot,μ}$ |
| 5 | A |
| 6 | B |

Table 6 Maximum number $C\_{PDCCH}^{max,slot,μ}$ of non-overlapped CCEs in X slots

|  |  |
| --- | --- |
| $$μ$$ | Maximum number of non-overlapped CCEs per X slots and per serving cell $C\_{PDCCH}^{max,slot,μ}$ |
| 5 | C |
| 6 | D |

***Observation 4:*** *Existing method to indicate PDCCH monitoring type configuration and corresponding limitations can be reused to indicate multi-slot level PDCCH monitoring.* ***Proposal 4:*** *For multi-slot level monitoring, it is preferred to define new limitation tables for monitored PDCCH candidates/non-overlapped CCEs per multiple slots and introduce a configuration to indicate multi-slot level PDCCH monitoring in PDCCH-config.* |

### R1-2100851 (Sony)

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| 1. **: UE PDCCH monitoring complexity can be reduced by modifying the configuration of search space set and CORESET, or alternatively by limiting the maximum number of BD/CCE per slot, but with potential link performance degradation.**

To avoid the issue introduced by the limitation of maximum BD/CCE per slot, mixed numerology operation is supported in Rel-15/16. e.g. 240 kHz subcarrier spacing for SSB and 120 kHz subcarrier spacing for PDCCH/PDSCH/PUSCH/PUCCH/PRACH. Thus, a mixed numerology where small SCS for PDCCH and large SCS for PDSCH/PUSCH/PUCCH can be considered for 52.6GHz-71GHz frequency band to alleviate PDCCH monitoring burden. However, for mixed numerology, when performing FFT, FFT size switching is needed from PDCCH to PDSCH/PUSCH/PUCCH, which would introduce extra processing complexity. Moreover, extra symbol gaps may also be needed for FFT switching operation. 1. **: UE PDCCH monitoring complexity can be reduced by using mixed numerology between PDCCH and other physical channels but with potential extra complexity and decreased time efficiency for FFT size switching.**

Try to manage the PDCCH monitoring and decoding complexity as well as guarantee the downlink performance, another effective scheme is to define a new time unit for new SCSs, like multi-slot. In this solution, the definition of time unit can rely on the SCSs difference. e.g., for Rel-15 120kHz and new SCS 960kHz, 8 slots in Rel-15 could be grouped into one time unit for the 52.6GHz-71GHz frequency range. In Rel-16 specifications, the time unit with span is supported, thus the processing on span can be referred for the design on new time unit. Together with PDCCH repetitions described in the next section, this solution could reduce PDCCH monitoring complexity and guarantee the DL BLER performance relatively. The link processing details of PDCCH monitoring, scheduling and new signaling for new time unit and the corresponding solutions aiming at a low impact to specification could be discussed further. 1. **: UE PDCCH monitoring complexity can be reduced by operating on a new time unit like multi-slot.**

With the above analysis and discussions among the three solutions, we would like to present the following proposal.1. **: For larger SCS in the 52.6GHz-71GHz frequency range, comprehensive consideration of UE monitoring complexity reduction together with UE power-saving and DL performance guarantee, define a new time unit like multi-slot could be a proper solution.**
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### R1-2100893 (LG)

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| **Observation #1: UE processing limit for 480 kHz and 960 kHz could be newly defined per slot. But, increasing the capability of handling PDCCH during a fixed time may lead to UE implementation complexity and power consumption. In addition, if the number of CCEs per slot is defined as too small value, support for PDCCH with large AL may be limited.**There are two simple ways to determine the length of a slot-group. The first way is to set the reference length regardless of actual SCS configuration. For instance, the slot length corresponding to 120 kHz SCS can be used as a reference length since 120 kHz is the smallest SCS that could be configured in FR-X. In this case, if one slot length corresponding to 120 kHz SCS is set to the reference length, then the consecutive four slots are used as slot-group for 480 kHz SCS, and consecutive eight slots are used as slot-group for 960 kHz SCS. Another way is to use a new PDCCH monitoring time unit with capability signalling. A preferred reference length can be signalled for each UE, and this length can be used as a basic time unit for PDCCH monitoring. Regarding the PDCCH monitoring per slot-group, associated procedures such as overbooking and dropping may also be enhanced. For example, if consecutive M slots for 960 kHz SCS is set to a slot-group for PDCCH monitoring, then SS set dropping due to overbooking would be performed in unit of slot-group. With this, additional restriction on PDCCH monitoring may be considered, e.g., by applying overbooking/dropping rules for some part of slots within a slot-group.**Proposal #1: Considering simplified UE implementation and potential power consumption reduction, support slot-group based PDCCH monitoring where the maximum number of PDCCH candidates and non-overlapping CCEs are defined per slot-group and the number of slots for slot-group can be determined based on reference SCS (e.g., 120 kHz) or UE capability.**In addition, SS set configuration can also be set appropriately for the slot-group. Through SS set configuration based on slot-group, PDCCH monitoring occasion could be adjusted properly (e.g., restricted), and then, additional power saving effects could be expected. For slot-group based PDCCH monitoring, specifically, SS set configurations such as periodicity (and offset) can be configured to a value larger than M (or a multiple of M) slots. Accordingly, duration may be limited to be configured with less than M (or a multiple of M) slots. Moreover, it can be discussed how to handle the case where the slot-group boundary does not exactly match the periodicity and duration configurations. Therefore, through slot-group based PDCCH monitoring configuration and associated SS set configurations, it can be further expected to reduce the UE implementation burden or power consumption. **Proposal #2: Consider to configure PDCCH monitoring occasions to be confined within the slot-group (or multiple of slot-groups), by using search space set configuration parameters (e.g., periodicity, offset, and duration).**  |

### R1-2101110 (Xiaomi)

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| With three SCSs, 120kHz and 480/960kHz are all specified, it may be not necessary to support all the three SCSs for NR 52.6-71GHz especially considering the complexity for high speed processing for 480/960kHz. Since 120kHz is already supported in FR1/2, it is backward compatible to support 120kHz as a default/ mandatory SCS and 480/960kHz as optional. The PDCCH monitoring capability for 120kHz per slot can still reuse the one defined in current spec as a mandatory capability. And the PDCCH monitoring capability for 480/960kHz per slot can be defined as optional capability. And even for the PDCCH monitoring capability for 480/960kHz, different UE capabilities can also be considered, for example UE cap1 supports relatively lower PDCCH candidate numbers and non-overlapped CCE numbers than UE cap2, which allows more flexible UE implementation and gNB scheduling for NR 52.6-71GHz. ***Proposal 1: The PDCCH monitoring capability for 120kHz per slot can still reuse the one defined in current spec as a mandatory capability. And the PDCCH monitoring capability for 480/960kHz per slot can be defined as optional capability.******Proposal 2:*** ***For PDCCH monitoring capability for 480/960kHz, different UE capabilities can be considered*** ***to allow more flexible UE implementation and gNB scheduling for NR 52.6-71GHz.***Similar PDCCH monitoring span as in R16 URLLC can be considered for NR 52.6-71GHz. In R16 URLLC, PDCCH monitoring span (X,Y) is defined as number of consecutive symbols in a slot where the UE is configured to monitor PDCCH. Each PDCCH monitoring occasion is within one span. If a UE monitors PDCCH on a cell according to combination (X,Y), the UE supports PDCCH monitoring occasions in any symbol of a slot with minimum time separation of X symbols between the first symbol of two consecutive spans, including across slots. A span starts at a first symbol where a PDCCH monitoring occasion starts and ends at a last symbol where a PDCCH monitoring occasion ends, where the number of symbols of the span is up to Y.With some little modification, for example, change the unit of X/Y from symbol to slot, a multi-slot PDCCH monitoring span can be defined. That is a span contains X slots and the PDCCH monitoring occasion are located in the first Y slots within the X slots. For SCS 480/960kHz, from our point of view, it is necessary to have this multi-slot span (X/Y) to allow sparse PDCCH monitoring in every X slots. For SCS 120kHz, since the current spec already support it with single slot PDCCH monitoring capability, multi-slot span PDCCH monitoring is not that necessary compared to 480/960kHz.***Proposal 3: Similar PDCCH monitoring span (X/Y) as in R16 URLLC can be considered for NR 52.6-71GHz by modifying the unit of X/Y from symbol to slot.******Proposal 4: It is necessary to define multi-slot span (X/Y) to allow sparse PDCCH monitoring in every X slots for the newly introduced SCS 480/960kHz.***However, compared with defining PDCCH monitoring capability per single slot, defining PDCCH monitoring capability per multi-slot span would allow gNB scheduling DCI in a bursty way, for example when X=8,Y=1. And it may cause the UE to spend more time on decoding all the DCIs scheduled in a DCIs burst, which will increase the total processing time for the scheduled PDSCH/PUSCH since UE has to decoding the DCI first. For example, with maximum number of B1/C1 of BDs/CCEs for PDCCH monitoring per single slot, UE is able to decode the all the DCIs in PDCCH in 1 symbol from the end of the PDCCH. But with maximum number of 4\*B1/4\*C1 of BDs/CCEs for PDCCH monitoring per multi-slot span (4/1) and gNB scheduling DCI in a bursty way, UE may need extra 2 symbols to guarantee to decode the all the DCIs in PDCCH, thus cause the decoding time of PDSCH(N1) and preparation time of PUSCH(N2) may need to be extended as well.***Proposal 5: Impacts on PDSCH/PUSCH processing time(N1/N2) may need be considered if defining maximum number of BDs/CCEs for multi-slot span PDCCH monitoring .*** |

### R1-2101195 (Samsung)

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| **Observation 1:** New BD and CCE limits with high SCS (480KHz and 960KHz) for NR from 52.6 GHz to 71 GHz is needed.**Observation 2:** PDCCH monitoring burden is high due to short TTI at high SCS (480KHz and 960KHz).Follow the same principle from Rel-16, a combination (X, Y) can be reused, such that X limits the PDCCH monitoring gap, while Y limits a PDCCH monitoring duration. Both X and Y can be extended from a number of symbols to a number of slots. The minimum PDCCH monitoring gap X should be larger than one slot, so that UE can distribute PDCCH processing/monitoring burden over multiple slots. For maximum PDCCH monitoring span, Y, the applicable value for Y can be same as Rel-15, i.e. one slot, slot-based PDCCH monitoring. Alternatively, Y can also be multiple slots to provide more PDCCH monitoring occasions and higher scheduling flexibility to NW. As UE expects much narrower beam direction from 52.6GHz to 71GHz compared with FR1 or FR2, the additional occasions when Y is larger than one slot can be used to for PDCCH receptions associated with different beam directions. In practice, UE can support multiple applicable values for combination (X, Y). The larger X value is, the more PDCCH monitoring burden reduction UE achieves. To provide more configuration or scheduling flexibility to NW, multiple combinations of (X, Y) can be supported for multi-slot span based PDCCH monitoring at high SCS, such as 480KHz and 960KHz. The combination (X, Y) can either be determined based on UE capability or predetermined for applicable SCS configurations, such as , $μ=5,or 6$.**Proposal 1: Support multi-slot span based PDCCH monitoring based on combination (X, Y), where the minimum PDCCH monitoring gap X is larger than one slot, and the maximum PDCCH monitoring span Y is one or more slots, for SCS of 480KHz and 960KHz.**However, there are some potential issues with multi-slot span based PDCCH monitoring. Firstly, the extended span gap will increase latency. A scheduling delay of (X - Y) slots can be large for some cases, such that X is much larger than Y, or Y is small, e.g. 1. In addition, there will be some loss of data rate if only single PDSCH/PUSCH scheduling per slot is supported. To overcome those issues, adaptation on combination (X, Y) can be considered when a UE is capable of supporting multiple combinations (X, Y). For example, when a UE reports a capability of multiple combinations (X, Y), the UE can be indicated with a selected combination (X, Y) from the multiple combinations based on L1 signaling. The UE can deactivate or activated some PDCCH monitoring occasions according to the PDCCH configuration limitations based on the selected combination (X, Y). Meanwhile, UE can perform joint adaptation on maximum number of BDs based on the indicated (X, Y), if the BD/CCE budget is defined per combination (X, Y), In addition, a UE can report its preferred minimum multi-slot span gap, X, and/or maximum multi-slot span Y according to UE requirements on power savings, latency, and data rate. **Proposal 2: Support adaptation and UE assistance information report for X and/or Y when UE supports multiple combinations (X, Y).**As $M\_{PDCCH}^{max,slot, μ}$ and $C\_{PDCCH}^{max,slot, μ}$ are quite small for SCS of 120KHz, there is no much room to reduce the BD/CCE limit for higher SCS. PDCCH blocking may become an issue when the BD/CCE limit is too small. Therefore, it’s better to consider BD/CCE limits per multi-slot span for high SCS, such as $μ=5, or 6$.**Proposal 3: Support maximum number** $M\_{PDCCH}^{max,(X,Y), μ}$ **of PDCCH candidates per multi-slot span for combination (X, Y), where X >1 slots, Y>=1 slots, and** $μ=5, or 6$**.****Proposal 4: Support maximum number** $C\_{PDCCH}^{max,(X,Y),μ} $**of non-overlapped CCEs per multi-slot span for combination (X, Y), where X >1 slots, Y>=1 slots, and** $μ=5, or 6$**.****Proposal 5: For multi-slot span based PDCCH monitoring based on combination (X, Y), support limitations on search space set configurations, including*** **PDCCH monitoring periodicity,** $k\_{s},$
* **PDCCH monitoring duration,** $T\_{s}.$

**Proposal 6: Support PDCCH candidates allocation/dropping per a span over multiple slots.** |

### R1-2101307 (Ericsson)

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| While a large range of search space monitoring periodicities have been supported since Rel-15, the UE PDCCH processing capabilities have been defined only on a per slot basis. For the multi-slot PDCCH monitoring approach discussed in the previous section, it will be necessary to define UE processing capabilities on a per-slot bundle basis considering the following: * We can view the UE PDCCH processing capabilities defined in Rel-15 as being define for a slot bundle size of $B=1$. A search space can have a monitoring periodicity that is an integer multiple of the bundle size, which is any positive integer allowed in the Rel-15 specs since $B=1$.
* For the example of PDCCH monitoring every 4 slots in the above, UE PDCCH processing capabilities for the bundle size of $B=4$ slots will need to be defined. For this bundle size, a search space can be configured to have a monitoring periodicity that is an integer multiple of the bundle size, which, in this example, can be 4, 8, 20 and so forth.
1. The monitoring periodicity of search space is an integer multiple of the bundle size B used to define UE PDCCH processing capabilities per bundle of B slots.

The potential reduction of UE PDCCH processing capabilities per slot shown previously presents difficulties to maintain the same scheduling framework and flexibility as Rel-15 NR. It would impose substantial negative impacts to Rel-17 NR operation in 52.6 – 71 GHz if the UE PDCCH processing capabilities per multi-slot monitoring period remain as restrictive when the UE is configured to monitor the PDCCH every $B$ slots. Therefore, it will be beneficial for NR operation in 52.6 – 71 GHz to scale UE PDCCH processing capabilities per $B$-slots with the bundle size B:$$N\_{BD, μ}^{B-slot}≅B×N\_{BD, μ}^{slot}$$$$N\_{CCE, μ}^{B-slot}≅B×N\_{CCE, μ}^{slot}$$1. A first approach to define the UE PDCCH processing capabilities when PDCCH monitoring per multiple slots is deployed for larger SCS is to scale the UE PDCCH processing capabilities per $B$ slots with the bundle size B. That is, the bundled UE PDCCH processing capabilities are $N\_{BD, μ}^{B-slot}≅B×N\_{BD, μ}^{slot}$ and $N\_{CCE, μ}^{B-slot}≅B×N\_{CCE, μ}^{slot}$.

With this first capability scaling solution, it is in principle possible to support any bundle size. However, it may be difficult or impractical for UE implementation to optimize the hardware and software timelines to support various required UE processing capabilities associated with arbitrary flexible bundle sizes. It will be beneficial for RAN1 to narrow down the bundle size values to those beneficial to system operations such that the specs and implementation are not over-burdened.1. RAN1 strives to narrow down the supported PDCCH monitoring bundle size values to those beneficial to system operations and implementation.

Toward narrowing down the supported PDCCH monitoring bundle values, a second possible solution is to maintain the same scheduling framework and capacity as a 120 kHz SCS system for larger SCS with PDCCH monitoring per multiple slots. For instance, PDCCH monitoring every $B=4$ slots can be deployed for 480 kHz SCS. The UE PDCCH processing capabilities per 4-slot monitoring bundle can then be defined as$$N\_{BD, μ=5}^{4-slot}=N\_{BD,μ=3}^{slot}$$$$N\_{CCE,μ=5}^{4-slot}=N\_{CCE,μ=3}^{slot}$$Similarly, the UE PDCCH processing capabilities per 8-slot monitoring bundle for 960 kHz SCS can then be defined as$$N\_{BD,μ=6}^{8-slot}=N\_{BD,μ=3}^{slot}$$$$N\_{CCE,μ=6}^{8-slot}=N\_{CCE,μ=3}^{slot}$$In other words, the UE capability for BD/CCE per B-slot bundle for a larger SCS (480 or 960 kHz) is the same as the per-slot capability for 120 kHz.1. A second approach to define the bundled UE PDCCH processing capabilities when PDCCH monitoring per multiple slots is deployed for larger SCS with a PDCCH monitoring frequency equal to that of 120 kHz SCS is to maintain the same UE processing capabilities per-slot as in a 120 kHz SCS system. That is, the bundled UE PDCCH processing capabilities are $N\_{BD, μ}^{2^{μ-3}-slot}=N\_{BD,μ=3}^{slot}$, and $N\_{CCE, μ}^{2^{μ-3}-slot}=N\_{CCE,μ=3}^{slot}$.
2. If arbitrary monitoring bundle size of $B$ is supported for UE capability scaling Option 2, i.e., $B\ne 4$ for 480 kHz SCS or $B\ne 8$ for 960 kHz SCS are supported, the bundled UE PDCCH processing capabilities are scaled relative to those for the 120 kHz SCS by a factor of $\left⌈\frac{B}{2^{μ-3}}\right⌉$.
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### R1-2101321 (CEWiT)

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| **Proposal 1:** **Support for** **dynamic adaptation of the parameters related to PDCCH monitoring, that are configured semi statically, in order to reduce number of blind decodings.**PDCCH decoding is performed blindly over all the available control channel elements (CCE), for all aggregation levels in all the configured search space sets until the limit of number of BDs per slot is achieved. A legacy UE can be configured with up to 10 search space sets. However, for the UEs with lesser amount of data to transmit/receive, the number of scheduled DCIs per slot may be less. Similarly, PDCCH decoding is performed for all the DCI formats configured for that search space set. However, in most cases, all DCI formats would not be scheduled in a slot. Performing blind decoding over all the search space sets and all DCI formats consumes unnecessarily more time and power. If details on the scheduled search space sets and DCI formats are signalled to a UE dynamically, then enormous time and power consumed for PDCCH blind decoding will be saved. There is also a possibility of early detection of DCI in conventional BD process. Performing blind decoding over remaining PDCCH candidates is unnecessary in that case. . Some mechanism to indicate the early termination will help to avoid this wastage.**Proposal 2:** **Dynamic indication of scheduled search space sets, DCI formats, DCI termination etc. is supported.**  |

### R1-2101373 (Apple)

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| In summary, RAN1 should support multi-slot monitoring and determine the BD/CCE limits over a group of slots (defined as a slot group/nominal monitoring unit). **The slot-group size can be defined based on a reference SCS and the PDCCH monitoring occasions should be defined per slot group with UE support for different Types that can be identified by the UE as a capability.*****Proposal 1:*** *slot-based and span-based PDCCH monitoring should not be applicable to Rel-17 UEs.* ***Proposal 2:*** *RAN1 should support multi-slot monitoring and determine the BD/CCE limits over a group of slots (defined as a slot group/nominal monitoring unit). The slot-group size can be defined based on a reference SCS.* ***Proposal 3****: RAN1 should define the PDCCH Monitoring Occasions per slot group. The MO could be defined as follows:** *Type 1: For all the slots in the slot group, PDCCH monitoring occurs within the first X symbols of the multiple slots*
* *Type 2: For all the slots in the slot group, PDCCH monitoring occurs on any span of X consecutive symbols within the multiple slots.*
* *Type 3: All PDCCH monitoring occasions can be in any OFDM symbol of a slot-group with a minimum time separation between 2 consecutive transmissions of the PDCCH.*
	+ *X : Number of OFDM symbols within which the monitoring occasion occurs,*
	+ *Y: minimum number of OFDM symbols between the start of different PDCCH Mos*
	+ *Z: Slot group size*

***Proposal 4:*** *Overbooking and dropping are performed per slot group.* |

### R1-2101418 (Convida Wireless)

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| Like Rel-16 URLLC PDCCH monitoring span (X, Y) definition, it can be extended to the mobile broadband (EMBB) service for NR from 52.6 GHz and above with few modifications. The PDCCH monitoring span (X, Y) for higher SCS/numerology (e.g. SCS 960 kHz) where the first number X is the number of slots between the beginning of two consecutive monitoring occasions, the second number Y is the number of slots or symbols needs to be monitored in a monitoring occasion. Rel-16 PDCCH/DCI span, it supports limited span like (X, Y) = (2, 2), (4, 3), and (7, 3). Note in Rel-16, the value of X and Y is based on units of symbols. Therefore, the X and Y supported in Rel-16 may not be suitable for NR from 52.6 GHz and above. For NR from 52.6 GHz and above, the duration per span may be across several slots to meet the scheduling requirement due to the number of PDCCH candidate and nonoverlapping CCEs being reduced per slot. The UE can be configured by gNB to monitor PDCCH with the maximum number of PDCCH candidates and nonoverlapping CCEs defined per slot as in NR Rel-15/16 or defined per span for the maximum number of PDCCH candidates and non-overlapping CCEs defined per span. An example of a PDCCH monitoring span shown in Figure 1. In Figure 1, we assume a configuration of PDCCH monitoring span for SCS = 960 KHz. For this example, let a span (X=4, Y=4) is configured, note the unit for X and Y can be either based on number of slots or symbols. it means there are PDCCHs need to be monitored in Y=4 slots/56 symbols and each PDCCH monitoring occasion are separated by X=4 slots/or 56 symbols.**Figure 1**: An exemplary PDCCH monitoring span for NR from 52.6 GHz to 71 GHz.***Proposal 1. PDCCH monitoring can be either based on per slot as Rel-15/16 or per span for NR from 52.6 to 71 GHz.***  |

### R1-2101454 (Qualcomm)

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| For the introduction of new high SCSs, i.e., 480kHz and 960kHz, the aspects of processing timeline should be revisited. As suggested in the WID [2], the study involves new UE capability related to the processing timeline. Many of the UE capabilities are already numerology dependent and the “slot” is commonly used as a reference time grid to confine the capabilities. For example, in Rel-15, UE’s capability for PDCCH monitoring, including the monitoring occasion placement, maximum number of PDCCH candidates and non-overlapped CCEs, is determined per slot. However, the per-slot PDCCH monitoring capability may be too restrictive for the new SCSs; due to the short slot length, the maximum number of BD/CCE supported per slot may be too small, which can harm the scheduling flexibility and performance. The appropriate numbers of blind decoding and non-overlapped CCEs for the high SCSs need further discussion in Rel-17, Proposal 1: For new SCSs, support the per-slot PDCCH monitoring capability and further study on the number of BD and non-overlapped CCE.In Table 1, the projected maximum numbers of PDCCH blind decoding and non-overlapped CCEs per slot for the new numerologies are shown. The projection is based on the log-linear regression from the values for existing numerologies with respect to $μ$. Although any physical implementation factors are not accounted, the projected numbers would be a feasible reference to show the trend. As discussed, for the per-slot PDCCH monitoring capability, the numbers of blind decoding and CCEs may be strictly limited for high SCSs.Table 1. Projected values of maximum numbers of blind decoding and non-overlapped CCEs per slot.

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| --- | --- | --- | --- |
| $$μ$$ | Slot length (*μ*s) | # BD | # CCE |
| 0 | 1000 | 44 | 56 |
| 1 | 500 | 36 | 56 |
| 2 | 250 | 22 | 48 |
| 3 | 125 | 20 | 32 |
| 5 | 31.25 | [10] | [18] |
| 6 | 15.625 | [8] | [14] |

Additionally, if the UE is expected to monitor PDCCH in every slot, the micro-sleep opportunities decrease due to the short slot length and the power efficiency during the connected mode would be degraded. Therefore, for the high SCSs that would be introduced in Rel-17, a new time basis, e.g., a bundle of slots, can be considered to confine the UE capabilities.Proposal 2: Multi-slot based PDCCH monitoring capability should be considered for new SCSs with short slot lengths. An example of the per-span PDCCH monitoring capability is shown in Table 2. In the table, the span-based capability is represented by a combination (*X*, *Y*), where *X* is the minimum separation (in symbols) between two consecutive spans, and *Y* is the maximum length of the span (in symbols). Note that, in Table 2, *X*=56 for *μ*=5 and *X*=112 for *μ*=6 amount to 125*μ*Sec separation and the corresponding numbers of BD and CCEs are the same as those for SCS 120kHz. Thus, at least similar extent of scheduling flexibility and micro-sleep opportunity as SCS 120kHz would be achieved by per-span PDCCH monitoring.Proposal 3: The per-span PDCCH monitoring capability in Rel-16 should be extended to define the multi-slot based PDCCH monitoring capability for high SCSs.Table 2. Example of per-span PDCCH monitoring capability for SCS 480kHz and 960kHz.

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| *μ* | Maximum number of monitored PDCCH candidates | Maximum number of non-overlapping CCEs |
| (28, 3) | (56, 3) | (112, 3) | (28, 3) | (56, 3) | (112, 3) |
| 5 | 10 | 20 | 40 | 18 | 32 | 56 |
| 6 | 8 | 10 | 20 | 14 | 18 | 32 |

As discussed in Section 2.1, it is desirable to support both per-slot and per-multi-slot PDCCH monitoring capabilities for the high SCSs. However, it needs further discussion which capability should be regarded as the baseline, considering the impact on basic procedures, such as acquisition of SIB1, RAR monitoring, and paging, etc.Proposal 4: For the high SCSs, support both single and multi-slot based PDCCH monitoring capabilities and further study which one should be the default capability.As an alternative switching mechanism, particularly for the unlicensed band operation, search space set group switching can be considered. In this case, each search space set group may be configured for either per-slot or per-span PDCCH monitoring. For example, search space set group 0 (i.e., the default group) can be configured with per-slot PDCCH monitoring and used when the UE is outside the channel occupancy time. On the other hand, search space set group 1 can be configured with per-span PDCCH monitoring and used during a COT. Although search space set group switching has dedicatedly been used for NR-U operation in Rel-16, the discussion on the extension for licensed band operation is in progress in Rel-17 UE power saving WI. Therefore, if supported for the licensed band operation, search space set group switching will provide more dynamic transition between per-slot and per-span PDCCH monitoring, both for unlicensed and licensed band operation.Proposal 5: For the high SCSs, support a dynamic switching mechanism between single and multi-slot based PDCCH monitoring capabilities.Observation 1: Bandwidth part switching and search space set group switching mechanisms can be considered as candidate switching mechanism between single and multi-slot based PDCCH monitoring. |

### R1-210606 (NTT DOCOMO)

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| ***Proposal 1****: PDCCH processing limitation values should be defined per longer time duration than a slot to avoid excessive reduction of PDCCH processing limits.*In our view, at least PDCCH monitoring of once in multiple slots should be applied for 480 kHz and 960 kHz SCS as basic capability on PDCCH monitoring to reduce the UE burden/power consumption. Then, more frequent PDCCH monitoring than once in multiple slots (including PDCCH monitoring in every slot) can be investigated as potential optional capability on PDCCH monitoring for 480 kHz and 960 kHz SCS to achieve higher scheduling flexibility.***Proposal 2****: The feasibility to apply UE feature group 3-1 as mandatory for above 52.6 GHz operation with 480/960 kHz SCS should be discussed.** *If not feasible, how to treat FG 3-1 for above 52.6 GHz operation with 480/960 kHz SCS needs to be discussed*

***Proposal 3****: PDCCH monitoring periodicity of once in multiple slots should be considered as basic capability on PDCCH monitoring for above 52.6 GHz operation with 480/960 kHz SCS.* |

## Topic A2: PDCCH Extensions for e.g. Coverage, Reliability

### R1-2100058 (Lenovo, Motorola Mobility)

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| With high SCS values, the absolute duration of the slot is greatly reduced and moreover, when single DCI can schedule multi-PDSCH/PUSCH over multiple slots, it might be beneficial to consider longer duration than 3 symbols for CORESETs. Multiple benefits can be associated with longer duration:* Better support for higher aggregation levels for better reliability
* More resources available for CORESET, but with same or even reduced duration in absolute time
* More symbols available to allow TDM multiplexing between DM-RS and control information
	+ Benefit of a DM-RS symbol with continuous frequency resources will account for better channel estimation with higher SCS values.

In fact, for very high SCS value such as 960kHz, even an entire slot for PDCCH can be considered to allow for only single PDCCH monitoring occasion within a slot.***Proposal 5: For supporting NR between 52.6 GHz and 71 GHz with high subcarrier spacing values including 480kHz and 960kHz, CORESET duration longer than 3 symbols should be supported:**** ***FFS: Maximum duration up to 14 symbols in a slot.***

***Proposal 6: For supporting NR between 52.6 GHz and 71 GHz with high subcarrier spacing values including 480kHz and 960kHz, CORESET structure with only TDM between the DM-RS symbols and control information should be supported.*** |

### R1-2100058 (Nokia, Nokia Shanghai Bell)

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| There are two basic solutions shown in Figure 2 to balance the PDCCH coverage with the repeated PDSCH: * Option 1: Mixed numerology between PDCCH and PDSCH: use a lower SCS, such as 120 kHz, for PDCCH. This is feasible from phase noise point of view and would minimize changes to PDCCH. On the other hand, this is not allowed in Rel. 15/16 NR.
* Option 2: Increased number of symbols available for PDCCH: This can be done either by defining a CORESET with increased length, or by means of CORESET repetition (of existing length).

We think that these two solutions need to be studied, and at least one solution for improved PDCCH coverage needs to be supported.   ***Proposal 4:****Support improved PDCCH coverage for the cases of high SCS* (i.e. Y>3)Figure 2. Candidate options to improve PDCCH coverage. |

### R1-2101418 (Convida Wireless)

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| There are several advantages to reduce the DCI format payload size for NR from 52.6 GHz and above. The first reason is to enhance the coverage and increase the reliability for DCI reception. A DCI format with a smaller payload achieves better reliability and coverage than the normal DCI (e.g. DCI format 1\_0/1\_1) with the same aggregation level (AL). The second reason is to reduce PDCCH blocking probability and enhance the scheduling flexibility. This is because DCI with less size consumes less PDCCH resources and a lower AL may be applied so the probability that PDCCH can be transmitted in the nearest CORESET after the arrival of data. The third reason is to reduce the decoding complexity and potentially save UE power consumption. Also, the presence of a new compact DCI format 1\_x as the compact format may increase the number of BDs for a UE (note: number of BD for a UE = number of PDCCH candidates multiply by the number of DCI format sizes). Therefore, like compact DCI for URLLC in Rel-16, a new compact DCI format 1\_x can be proposed for NR from 52.6 GHz to 71 GHz. Plus, gNB can configure the UEs to monitor only the compact DCI format 1\_x instead of DCI format 0\_0/1\_0 and 0\_1/1\_1 so that the total number of blind decodes won’t increase for a UE. In addition, gNB may dynamically or semi-statically switch between the DCI formats that are supposed to be monitored by the UE. For example, gNB may transmit MAC-CE to switch the monitoring of DCI format 0\_0/1\_0 or 0\_1/1\_1 to DCI format 1\_x.***Proposal 2. A new compact DCI format 1\_x for large numerology/SCS like 480 KHz and above should be studied for NR operation from 52.6 to 71 GHz.***  |

## Topic B: Multiple PDSCH/PUSCH by a single DCI

### R1-2100058 (Lenovo, Motorola Mobility)

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| In our accompanying contribution [3], we propose a new single DCI format to schedule multiple PDSCH and PUSCH. In our view, if such new DCI format can be agreed to be supported for high SCS values such as 480kHz and 960kHz, then PDCCH monitoring can be further reduced by restricting the need for UE to monitor other DCI formats for scheduling DL/UL such as DCI format 0\_1 and format 1\_1. If such restriction is supported, then the blind detection for a UE can be significantly reduced. ***Proposal 3: For supporting NR between 52.6 GHz and 71 GHz with high subcarrier spacing values including 480kHz and 960kHz, if a new DCI is agreed to schedule multiple PDSCH and/or multiple PUSCH, then restrictions on monitoring of other DCI formats (such as DCI format 0\_1/1\_1) should be supported.***Furthermore, additional restriction can be considered to further reduce the blind detections for UE. One possibility could be to consider only higher values of aggregation levels for monitoring any new DCI format(s) for high SCS values. This provides the benefit of better reliability for URLLC traffic. ***Proposal 4: For supporting NR between 52.6 GHz and 71 GHz with high subcarrier spacing values including 480kHz and 960kHz, if a new DCI is agreed to schedule multiple PDSCH and/or multiple PUSCH, then restrictions on certain aggregation levels (for example: lower aggregation levels) for new DCI should be supported.*** |

### R1-2100608 (MediaTek)

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| As a consequence of PDCCH monitoring enhancement, another discussed DL enhancement is PDSCH scheduling. In particular, the enhancement of multi-PDSCH scheduled by one DCI has been included in WI to improve data rate under the reduced UE PDCCH monitoring frequency with the help of cross slot scheduling. On the other hand, when the legacy per slot monitoring is configured, same slot scheduling is preferred to maximize the throughput. With the short slot duration of 480 kHz and 960 kHz, it is essential to design a feasible UE behavior of PDCCH monitoring within a slot to realize the same slot scheduling. Therefore, we propose to confine PDCCH monitoring within the first 3 symbols of a slot when per slot monitoring is configured with 480 kHz and 960 kHz SCSs. Proposal 4: For 480 and 960 kHz SCS, PDCCH monitoring is confined to be within the first 3 symbols of a slot when per slot monitoring is configured. |

### R1-2100644 (Intel)

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| In a companion contribution [2], multi-TTI scheduling for PDSCH and PUSCH transmissions is discussed. It is straightforward that a new DCI format will be introduced. Correspondingly, the new DCI format for multi-TTI scheduling need to be configured in the SS set configuration. As a simple extension, a SS set configuration can be configured with either a fallback DCI, a normal DCI for single-TTI scheduling or a DCI format for multi-slot scheduling. The DCI format for multi-PDSCH scheduling and multi-PUSCH scheduling may be configured together or separately. **Proposal 3: A SS set can be configured with*** **DCI format 0\_0/0\_1, or**
* **Normal DCI formats for single-TTI scheduling, or**
* **Normal DCI formats for multi-TTI scheduling**
	+ **FFS separate configuration for multi-PDSCH scheduling and multi-PUSCH scheduling**
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### R1-2101321 (CEWiT)

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| Scheduling of multiple PDSCHs using a single DCI can be used to reduce the time required for PDCCH monitoring. If each of the PDSCH is scheduled using an independent DCI, then the number of scheduled DCIs will be more. If multiple PDSCHs are scheduled by a single DCI, the number of scheduled DCIs will reduce, which in turn will require lesser number of PDCCH candidates to schedule a UE. This in turn requires lesser number of BD’s. Hence, if multiple PDSCHs are scheduled using single DCI, the number of BDs performed by the UE per slot can be reduced.**Proposal 3:** **Scheduling multi-PDSCH through single DCI is supported.** |

### R1-2101321 (Convida Wireless)

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| Single DCI can schedule multiple PDSCHs as shown in Figure 2. In Figure 2, a DCI schedule multiple (e.g. two) PDSCHs. In this example shown in Figure 2, the PDCCH monitoring frequency is reduced, thus it can reduce PDCCH decoding efforts for a UE. However, some DCI field like HARQ process number, TB indication, New data indicator and Redundancy version, etc. may not be shared for each scheduled PDSCH. If the single-to-multiple scheduling DCI format (e.g. DCI format 1\_y) with the DCI size is large (e.g. DCI > 120 bits) which it requires a larger CCE aggregation level, then PDCCH blockage may become higher thus degrading the scheduling performance. Therefore, PDCCH blockage needs to be avoided for single-to-multiple scheduling PDSCHs scenario.  **Figure 2**: Single DCI schedule multiple (e.g. two) PDSCHs.***Proposal 3. To avoid PDCCH blockage issue when single DCI scheduling multiple PDSCHs, the size of DCI format should be studied.*** Like the case that a single DCI scheduling multiple PDSCHs in a serving cell, there are several advantages to introduce a single DCI format scheduling multiple PDSCHs across multiple CCs for NR from 52.6 – 71 GHz. One of the major benefits is to enhance the scheduling flexible because less DCIs are transmitted especially slots duration is getting shorter for NR from 52.6 GHz and above. One example of a single DCI scheduling multiple PDSCH across multiple CCs are shown in Figure 4. In Figure 4, we assume there are two CCs are carrier aggregated in a cell group. gNB may signal the COT and LBT results to a UE, then the UE may only monitor PDCCH in a CC (e.g. CC 1). The UE does not need to monitor PDCCH from the other CCs in the same cell group thus it can save power consumption. One thing is worth to note that a single DCI schedule multiple PDSCHs across CCs is not impact by whether support of listen-before-talk (LBT) or not. In addition, a single DCI schedule multiple PDSCHs across multiple CCs can share the design of single DCI schedule multiple PDSCHs discussed in subsection 2.3. **Figure 4**: An exemplary for aggregated channel BW for (a) 2 GHz (b) 4 GHz with SCS = 120 KHz and assuming the maximum $BW\_{channel}=400$ MHz.***Proposal 4. Single DCI schedule multiple PDSCH across multiple CCs should be studied for NR operation from 52.6 to 71 GHz.***  |

## Topic C: Multi-Beam Aspects

### R1-2100058 (Lenovo, Motorola Mobility)

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| Another important aspect for PDCCH monitoring is related to directional LBT. Directional LBT may cause some issues comparing with omni-directional LBT. For example, different Tx beams used by gNB may correspond to different COTs, thus different CORESETs which are configured with different Tx beams by higher layer signalling may also correspond to different COTs. From power saving perspective, during a COT initiated by a gNB, a UE can stop monitoring the PDCCH occasions in the CORESET corresponding to a different COT, which can reduce the power consumption cause by blindly decoding. That is to say, after transmitting a PDCCH to a UE within a COT, the gNB will not transmit PDCCH to this UE in the CORESET corresponding to another COT until the current COT ends.***Proposal 7: For NR unlicensed bands between 52.6 GHz and 71 GHz with directional LBT based channel access mechanism, within a COT, PDCCH monitoring is nor supported in the CORESETs corresponding to other COTs (PDCCH monitoring restricted to monitoring corresponding to only one COT at a time)*** |

### R1-2100258 (Nokia, Nokia Shanghai Bell)

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| One more issue related to DL control seems to be operation of DCI format 2\_0 in a beam based system. In Rel. 15, DCI format 2\_0 contained only SFI, and from SFI point of view, UL and DL direction is clearly beam agnostic due to strong self-coupling between different panels. On the other hand, in R16 DCI format 2\_0 contains also other information, such as COT or SS-group switching trigger, RB-sets. Any of these pieces of information could become beam dependent. However, support for beam-dependent configurations of DCI format 2\_0 is not possible in FR2 currently. Although a UE can be indicated a change of active-TCI, DCI format 2\_0 PDCCH candidates and, payload location remains the same and thus cannot be beam specific.   ***Observation 2:*** *GC-PDCCH is an essential part of unlicensed band system, and there seems to be a need to support beam-dependent information, particularly if some form of directional LBT is chosen as coexistence mechanism.* ***Proposal 6:****Changes to DCI format 2\_0 may be beneficial for at least unlicensed 60GHz NR operation.*  |

### R1-2100893 (LG)

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| In Rel-16 NR-U, several fields such as RB set indicator, CO duration and SS set group switching trigger were introduced to DCI format 2\_0, in addition to SFI. However, for FR-X in Rel-17 where the use of directional beams may be essential, it can be worth considering the beam dependent GC-PDCCH configuration. In other words, it may be beneficial to give a spatial relation for a beam to which information of DCI format 2\_0 is applied. One simple conceivable method is to define some fields in DCI format 2\_0 separately for each beam. For example, RB set indicator and CO duration could be configured separately for each beam, but SFI could be configured as beam agnostic. Alternatively, a new field can be additionally introduced in DCI format 2\_0 to indicate the availability of each beam. In this method, UE receiving DCI format 2\_0 may determine the channel availability for each beam through a combination of the new field and existing fields (i.e., RB set indicator and CO duration). **Proposal #3: Consider per beam indication of available RB set, CO duration, and/or SS set switching by using DCI format 2\_0.** |

## Topic D: Cross-carrier scheduling

### R1-2100644 (Intel)

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| Cross-carrier scheduling is a quite useful feature for NR. Therefore, it is expected that cross-carrier scheduling between serving cells using SCS 120/480/960kHz can be supported. On the other hand, one more discussion point is the carrier aggregation (CA) between a cell with 52.6-71GHz frequency and a cell in FR2 or even FR1. From specification completeness point of view, such CA scenario could be supported, especially considering a PCell in lower frequency than 52.6-71GHz is more appropriate for coverage/robustness. On the other hand, if such kind of CA is supported and cross-carrier scheduling is considered, an extreme case could be that, a slot with SCS 15kHz is used to schedule up to 64 slots with SCS 960kHz. The scheduling capability needs to be carefully dimensioned. Without a clear motivation, we prefer to avoid unnecessary optimization for such extreme case. **Proposal 4: Cross-carrier scheduling of cell with 52.6-71GHz frequency from/to a cell of FR1 and FR2 is allowed by specification, however, additional enhancements are deprioritized unless a clear motivation is identified.** |

### R1-2101321 (Convida Wireless)

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| Like the case that a single DCI scheduling multiple PDSCHs in a serving cell, there are several advantages to introduce a single DCI format scheduling multiple PDSCHs across multiple CCs for NR from 52.6 – 71 GHz. One of the major benefits is to enhance the scheduling flexible because less DCIs are transmitted especially slots duration is getting shorter for NR from 52.6 GHz and above. One example of a single DCI scheduling multiple PDSCH across multiple CCs are shown in Figure 4. In Figure 4, we assume there are two CCs are carrier aggregated in a cell group. gNB may signal the COT and LBT results to a UE, then the UE may only monitor PDCCH in a CC (e.g. CC 1). The UE does not need to monitor PDCCH from the other CCs in the same cell group thus it can save power consumption. One thing is worth to note that a single DCI schedule multiple PDSCHs across CCs is not impact by whether support of listen-before-talk (LBT) or not. In addition, a single DCI schedule multiple PDSCHs across multiple CCs can share the design of single DCI schedule multiple PDSCHs discussed in subsection 2.3. **Figure 4**: An exemplary for aggregated channel BW for (a) 2 GHz (b) 4 GHz with SCS = 120 KHz and assuming the maximum $BW\_{channel}=400$ MHz.***Proposal 4. Single DCI schedule multiple PDSCH across multiple CCs should be studied for NR operation from 52.6 to 71 GHz.***  |

### R1-2101454 (Qualcomm)

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| For cross-carrier scheduling with different SCSs, in particular when the SCS of the scheduling cell is smaller than that of the scheduled cell, the memory requirement for buffering the Rx signal on the scheduled cell during the PDCCH processing may be excessive. In Rel-16, thus, the minimum preparation time for cross-carrier scheduled/triggered reception has been introduced (TS 38.214, Clause 5.5 for PDSCH and Clause 5.2.1.5.1a for aperiodic CSI-RS).With the introduction of new high SCSs, the related discussion should be continued. In the discussion, the following aspects may be highlighted: * Proper values and ranges of the minimum preparation time ($N\_{csirs}$ in Table 5.2.1.5.1a and $N\_{pdsch}$ in Table 5.5-1 of TS 38.214),
* Dependency and adaptation based on UE’s PDCCH monitoring capability (i.e., per-slot or per-span).

Proposal 6: In order to support cross-carrier scheduling, the PDSCH reception preparation time (as well as aperiodic CSI-RS reception) for new high SCSs should be investigated. |

## Topic E: Other

### R1-2100893 (LG)

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| Considering the efficient coexistence with Wi-Fi operating with nominal channel bandwidth of 2.16 GHz, NR in unlicensed FR-X band may need to be operated with carrier bandwidth comparable to Wi-Fi. However, since some UEs may not support carrier bandwidth up to 2.16 GHz, it should be considered multi-carrier based operation where each carrier has bandwidth narrower than 2.16 GHz (e.g. 400 MHz) but aggregated bandwidth through multiple carriers can reach to around 2.16 GHz. In such case, some measurements for the channel availability such as LBT result for each carrier can be identical over multiple carriers which overlap to the occupied channel bandwidth of Wi-Fi. To indicate these information to group of carriers efficiently, carrier-group based GC-PDCCH configuration can be considered. For instance, GC-PDCCH indicating available RB sets and CO duration can be configured per carrier-group instead of per each carrier, and the set of carriers within the carrier-group can share these information. For another instance, DL/UL data scheduling can be configured per carrier-group to reduce the amount of GC-PDCCH transmission instead of indicating to each carrier. With carrier-group based configuration, it can be beneficial with respect to the controllability of channel access or data channel scheduling in unlicensed FR-X band.**Proposal #4: Carrier-group based GC-PDCCH configuration for unlicensed FR-X band may be beneficial with respect to signalling efficiency.** |

### R1-2101110 (Xiaomi)

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| Search space set group switching is introduced in R16 NR-U for power saving propose and group switching time $P\_{switch}$ is defined for SCS 15-60kHz. To facilitate unlicensed band operation for NR 52.6-71GHz, group switching time $P\_{switch}$ should also be defined for 120/480/960kHz ***Proposal 6: Search space set group switching time*** $P\_{switch}$ ***should be defined for 120/480/960kHz.***The maximum search space periodicity in current spec is 2560 slots, and with SCS increased to 960kHz, the absolute time of the maximum search space periodicity will be decreased by 8 times. So new periodicity parameters may need to be introduced for the new SCSs, as well as the search space offset/duration parameters.***Proposal 7:*** ***New search space periodicity parameters, as well as the search space offset/duration parameters, may need to be introduced for the new SCSs.*** |

### R1-2101454 (Qualcomm)

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| Observation 2: Along with the multi-slot based PDCCH monitoring capability, DCI piggyback, as well as multi-PDSCH/PUSCH scheduling, may be considered to compensate the loss of scheduling flexibility and latency.Figure 1: Sparse PDCCH monitoring occasions with DCI transmission on PDSCH. |

# List of submitted TDocs

The following TDocs have been used to compile above summary:

**R1-2100058 PDCCH monitoring enhancements for NR from 52.6 GHz to 71GHz Lenovo, Motorola Mobility**

**R1-2100074 Discussion on the PDCCH monitoring enhancements for 52.6 to 71GHz ZTE, Sanechips**

**R1-2100150 Discussion on PDCCH monitoring OPPO**

**R1-2100241 Enhancement on PDCCH monitoring Huawei, HiSilicon**

**R1-2100258 PDCCH monitoring enhancements Nokia, Nokia Shanghai Bell**

**R1-2100371 PDCCH monitoring enhancements for up to 71GHz operation CATT**

**R1-2100430 Discussions on PDCCH monitoring enhancements for NR operation from 52.6GHz to 71GHz vivo**

**R1-2100608 PDCCH monitoring enhancement for 52.6-71 GHz NR operation MediaTek Inc.**

**R1-2100644 Discussion on PDCCH monitoring enhancements for extending NR up to 71 GHz Intel Corporation**

**R1-2100817 Discussion on PDCCH monitoring enhancement for NR beyond 52.6 GHz Spreadtrum Communications**

**R1-2100837 Discussions on PDCCH monitoring enhancements InterDigital, Inc.**

**R1-2100851 PDCCH enhancement for NR from 52.6GHz to 71GHz Sony**

**R1-2100893 PDCCH monitoring enhancements to support NR above 52.6 GHz LG Electronics**

**R1-2101110 PDCCH monitoring enhancement for NR 52.6-71GHz Xiaomi**

**R1-2101195 PDCCH monitoring enhancements for NR from 52.6 GHz to 71 GHz Samsung**

**R1-2101307 PDCCH Monitoring Enhancements Ericsson**

**R1-2101321 Discussion on PDCCH monitoring enhancements for NR above 52.6GHz CEWiT**

**R1-2101373 PDCCH monitoring enhancements for NR between 52.6GHz and 71 GHz Apple**

**R1-2101418 Consideration for PDCCH Monitoring for Supporting NR from 52.6 GHz to 71 GHz Convida Wireless**

**R1-2101454 PDCCH monitoring enhancements for NR in 52.6 to 71GHz band Qualcomm Incorporated**

**R1-2101606 PDCCH monitoring enhancements for NR from 52.6 to 71 GHz NTT DOCOMO, INC.**