**3GPP TSG RAN WG1 Meeting #102-e R1-2007038**

**e-Meeting, August 17th – 28th, 2020**

**Source: Moderator (Intel Corporation)**

**Title: Discussion summary of [102-e-NR-52-71-Waveform-Changes]**

**Agenda item: 8.2.1**

**Document for: Discussion/Decision**

# Introduction

In this contribution, we summarize all issues submitted on physical layer changes and aspects for supporting NR from 52.6 GHz to 71 GHz for RAN1 #102-e meeting. Section 2 and 3 contain summary of email discussions that took place during RAN1 #102-e.

# Summary of Views on Numerology and Bandwidth

The following is a summary of views on bandwidth, subcarrier spacing (SCS), FFT sizes, CP length, and other related issues to numerology.

Moderator asks companies to correct or fill in any missing information in the following table using colored text (to differentiate the changes). Based on the summary, moderator will check if there are some aspects where companies seem to have good alignment and propose some conclusions/agreements.

Table . Summary of views on bandwidth, subcarrier spacing (SCS), FFT size, CP length, and related issues to numerology

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| **Company Name** | **Bandwidth** | **SCS (for BWP)** | **FFT** | **CP** | **Notes** |
| Lenovo, Motorola Mobility | 800 MHz (for 240 kHz)1600 MHz (for 480 kHz)3.2 GHz (for 960 kHz) | 240 kHz,480 kHz, 960 kHz (for ~2 GHz) | Max 4096 | NCP: 240, 480, 960 kHz |  |
| Huawei, HiSilicon |  | 120, 240 kHz | Max 4096 | NCP:120, 240 kHz[ECP:480, 960 kHz] | SSB SCS:120,240 kHz for licensed240 kHz for unlicensed |
| Futurewei | 400 MHz | 480 kHz | Max 4096 |  | Larger BW achieved using CA |
| vivo |  | 120 kHz, 960 kHz |  | NCP: 120, 960 kHz |  |
| Fujitsu |  |  |  |  |  |
| Sony | 2.16 GHz (unlicensed)400 MHz (licensed) | 240 or 480 or 960 kHz | 4096 (960 kHz)8192 (480 kHz)16384 (240 kHz) |  |  |
| ZTE, Sanechips | 400 x N MHz2.16 GHz |  | Max 4096 |  | SSB SCS:240 kHz |
| MediaTek |  |  |  |  |  |
| CATT | 1 GHz | 240 kHz | Max 4096 | NCP: 240 kHz |  |
| Xiaomi |  |  |  |  |  |
| NEC | > 1 GHz | 240 kHz |  |  |  |
| TCL | ≤ 2.16 GHz |  |  |  |  |
| Mitsubishi  |  |  |  |  |  |
| Intel  |  | 480, 960 kHz |  | NCP:480, 960 kHz | ECP might be needed depending on MIMO TAE |
| Ericsson | ≤ 1.6 GHz  | ≤ 480 kHz |  |  | SSB SCS: 120/240 kHz |
| OPPO |  | 960 kHz |  |  |  |
| Samsung | 400 MHz21.6 GHz | 960 kHz (2.16 GHz)120 kHz (400 MHz) | Max 4096 | 120 kHz (NCP)960 kHz (NCP and/or ECP) |  |
| CMCC | ≤ 1.6 GHz | ≤ 480 kHz | Max 4096 |  |  |
| Spreadtrum  |  |  |  |  |  |
| LG Electronics | 800 MHz (240kHz) 1.6 MHz and/or 800 MHz (480kHz) | 240, 480 kHz |  |  | SSB SCS: 120kHz, 240 kHz  |
| InterDigital |  |  | Max 4096Min 512 |  |  |
| Apple | 400 x N MHz | ≤ 480 kHz |  |  |  |
| Convida Wireless |  |  |  |  |  |
| Charter |  | 960 kHz |  |  |  |
| NTT DOCOMO | Max: > 400 MHzMin: > 50 MHz | > 120 kHz | Max 4096 | ECP: 960kHz (if supported) |  |
| Qualcomm | ≤ 400 MHz (120kHz)≤ 21.6 GHz (960 kHz) | 120 kHz960 kHz |  |  |  |
| CAICT |  | 240 kHz 480 kHz (FFS) |  |  |  |
| WILUS |  |  |  |  |  |
| Nokia, Nokia Shanghai Bell | 400 x N MHz (N=1,2,3) | 120kHz960 kHz1920 kHz (only for OFDM) |  | ECP: 960 kHz |  |

# Summary of [102-e-NR-52-71-Waveform-Changes]

## 3.1 General Comments on SI

These are collection of comments on the SI or framework of licensed or unlicensed operation.

* From [5]:
	+ To support operation between 52.6 GHz and 71 GHz, a common framework should be shared for licensed and unlicensed operation for less standardization workload and specification burden.
	+ To figure out the required changes to NR using existing NR waveform, discussion on unlicensed operation can be prioritized.
	+ Based on the outcome, licensed operation can be supported by simply removing some unnecessary functionalities or adding essential functionalities if any.
	+ If it is possible that a spectrum is for unlicensed operation in a region but for licensed operation in another region, mechanism to allow UE to differentiate two types of operation should be considered at the beginning.
* From [17]:
	+ The study item shall support both licensed and unlicensed operation between 52.6 GHz and 71 GHz, and unlicensed band between 57 GHz and 71 GHz (i.e., 60 GHz unlicensed band) should be prioritized.
* From [30]:
	+ 60 GHz unlicensed band should be prioritized for this SI study.
	+ Short range high data rate D2D deployment scenario should be studied for above 52.6 GHz band.
	+ Higher priority should be given for CA case, where above 52.6 GHz is only used for SCell for throughput boosting.

**Discussion:**

Companies are suggesting having some agreement/conclusion on the focus and scope of the SI, especially regarding on licensed and unlicensed operation. Given that the already approved WI in RP-193229 approves work for both licensed and unlicensed, avoiding working on licensed and unlicensed operation might not be possible. However, moderator thinks we can still have some discussion on whether unlicensed operation should be prioritized or not.

Please comment further on the following:

* [The study item shall support both licensed and unlicensed operation between 52.6 GHz and 71 GHz] – *moderator note: may not need to agree or conclude given that WI approved (RP-193229) work for both licensed and unlicensed.*
* Unlicensed band operation should be prioritized for this SI study.

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| **Company** | **Comments** |
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## 3.2 General Comments on Numerology Study

The following are observations/proposals related to numerology study from the submitted contribution.

* From [5]:
	+ In order to achieve higher efficiency from signaling overhead and resource utilization perspective, wider channel BW beyond 400 MHz should be supported.
	+ Furthermore, Lager SCS than 120 kHz can be introduced to have small FFT size in case of wider channel BW and robustness to phase noise at the higher frequency
	+ The CP can be scaled following the SCS in the same way as NCP in Rel-15.
	+ The tradeoff between performance and cost should be taken into account in the discussion on how wide channel BW and SCS would be supported in the range from 52.6GHz to 71GHz.
* From [9]:
	+ The physical channel/signals with the potential impacts by the introducing of higher SCS for data and control channels are as follows,
		- (1) Type0-PDCCH SCS indication in MIB
		- (2) PRACH preamble
		- (3) UE processing capability and the required processing time for higher SCS
* From [15]:
	+ For selection of suitable SCS for the 52.6 – 71 GHz frequency range, it is important to perform link level evaluations with 90th percentile RMS delay spreads that are representative of a suitable range of deployment scenarios with different site densities, e.g., up to several tens of ns.
	+ Sufficient margin must also be left for other sources of time synchronization error.
* From [19]:
	+ Study the impact of channel bandwidth and numerology to physical signal/channel, e.g. the time line, SS/PBCH block, PT-RS and PDCCH monitoring capability
* From [20]:
	+ Study further on potential impacts (and relevant handling) due to the shortening of OFDM symbol duration and CP length by adopting larger SCS value.
	+ Whether/how to handle impact to cell coverage and/or beam switching time (e.g. by employing the extended CP and/or grouping multiple OFDM symbols as a unit)
* From [21]:
	+ Study multiples of 400 MHz up to 2 GHz is considered for above 52.6 GHz.
	+ Study potential coexistence issue with other RAT in the spectrum of 52.6 GHz to 71 GHz.
* From [22]:
	+ Down-select SCS based on the phase noise reduction requirements of transmission at < 71 GHz, the bandwidth requirements and the cyclic prefix required to mitigate the effect of the beam formed delay spread.
* From [23]:
	+ To support various wide bands and use cases for NR operation from 52.6 GHz to 71 GHz, a wide range of numerologies with the carrier aggregation need to be studied, also considering the LBT bandwidth (or the RB set) for co-existing issues, UE capability, processing time and power consumption.
* From [25]:
	+ The changes added to the current NR should be minimized.
	+ In this sense, only one or two SCSs are sufficient for 52.6 – 71 GHz band in our view
* From [29]:
	+ In addition to channel BW and link performance aspects, RAN1 should consider also implementation complexity associated with high SCSs when selecting the supported SCSs for above 52.6 GHz.
	+ Extend the numerology scaling framework defined in NR Rel-15 to higher numerologies with an appropriate range of integer values for μ.
	+ Maintain the maximum number of RBs supported by NR specification also for NR scenario above 52.6 GHz.

**Discussion:**

The general comments span multiple aspects such as factors that should be taken into account as part of the numerology discussion, to system components that get impacted from numerology, bandwidths that should be supported, and the baseline and design commonality with existing NR system. While it might be difficult to get everything down, there could be some benefits to agree on some general principles or general groundwork of the study, so that such description could be captured into the TR.

Please comment further on the following (including if you already have some suggestions for a TP with general description about the numerology study):

* Agree to add a paragraph(s) in the TR regarding:
	+ potential issues for consideration as part of the numerology selection and study,
	+ (if needed) general framework description (e.g. using 2μ ×15 subcarrier spacing to select candidates)
* The exact text could be worked on further if above is agreeable.

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| **Company** | **Comments** |
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## 3.3 SSB pattern and SSB/CORESET multiplexing

The following are observations/proposals related to SSB pattern and SSB/CORESET multiplexing aspect from the submitted contribution.

* From [2]:
	+ Multiplexing patterns 2 and 3 for SSB and CORESET for Type0-PDCCH better facilitate meeting the OCB requirement in NR-U-60.
* From [7]:
	+ SSB pattern could be re-designed whether higher SCS is supported or not. Transmission opportunities, timing and QCI of Rel-17 SSB should be considered.
* From [12]:
	+ Introduce groups of SCS in FR2 and all control/data communication will use the SCS from one such group.
	+ It is proposed to investigate how to transmit the indication about additional SS/PBCH candidate positions which can become available with existing FR2 numerologies or future new numerologies.
	+ It is proposed to investigate efficient transmission of MSI including the multiplexing patterns for both licensed and shared carriers.
* From [14]:
	+ When a large subcarrier spacing is defined, SSB pattern and multiplexing of SSB and CORESET0/RMSI need to be updated to accommodate beam switching time.
* From [15]:
	+ Do not design for SS/PBCH block sliding within a transmission window for >52.6 GHz operation.
	+ For NR operations in the 52.6 – 71 GHz band, consider only 120 and 240 kHz SCS for SS/PBCH blocks, as already supported in Rel-15/16.
	+ Consider reusing the SS/PBCH / CORSET0 multiplexing patterns as much as possible.
	+ If minor, targeted, enhancements to particular pattern(s) are beneficial, these can be considered.
		- SS/PBCH / CORESET0 multiplexing patterns 2 and 3 are restricted to very small RMSI payloads due to the small number (2) of available OFDM symbols for RMSI PDSCH.
		- SS/PBCH / CORESET0 multiplexing pattern 1, especially with non-zero offset O for the Type0-PDCCH monitoring occasions, is much less restrictive in terms of allowable RMSI payload due to the fact that SS/PBCH and RMSI PDCCH/PDSCH are time division multiplexed.
	+ Consider enhancements to SS/PBCH / CORESET0 multiplexing Pattern 1 as follows:
		- (1) Allow (240 kHz, 240 kHz) SCS,
		- (2) Support 6 symbol SLIV in Default Table A starting at OFDM symbols 2 and 8.
* From [17]:
	+ RAN1 shall study the SS/PBCH block pattern for the new numerology, taking into account the beam switching time between neighboring SS/PBCH blocks.
* From [20]:
	+ Consider the enhancements for the SSB transmission to provide more opportunities in FR-X unlicensed band.
	+ Study further how to multiplex SSB and corresponding CORESET#0 in case of using new numerologies such as 240/480 kHz SCSs for the DL signal/channels other than SSB.
* From [25]:
	+ Whether to introduce gap symbol(s) for beam switching time should be discussed not only for SSB but also for any signal/channels with beam switching in case that higher SCS such as 960 kHz is supported.
	+ For SSB and CORESET multiplexing, following aspects should be discussed:
		- Which SCS(s) is supported for SSB and which combination(s) of SCS between SSB and CORESET#0 is supported;
		- Whether only single numerology is supported as in Rel-16 NR-U or not;
		- Whether the number of supported SCSs for SSB should be minimized.
	+ Which multiplexing pattern between SSB and CORESET#0 is supported for each combination of SCS between SSB and CORESET#0:
		- What are minimum channel bandwidth, minimum required CORESET#0 bandwidth and minimum required bandwidth for RMSI PDSCH;
		- Whether beam sweeping overhead should be minimized by FDM between SSB and CORESET#0 and/or RMSI PDSCH
* From [27]:
	+ SSB design should be enhanced to match unlicensed band requirements.
* From [28]:
	+ SSB pattern in a slot should be further investigated for higher subcarrier spacing (e.g. candidate subcarrier spacings of 480kHz, 960kHz, or 1920kHz) taking into account a beam switching gap due to a RF interruption time of Tx/Rx beams and/or LBT gap in unlicensed spectrum.
	+ It should be further studied so that SS/PBCH block and CORESET#0/RMSI can be multiplexed in TDM/FDM within a slot considering multi-beam operation. And it may need to be designed so that it can be closely located without the gap between SSB and CORESET#0/RMSI for the operation of the unlicensed band in terms of channel access.
* From [29]:
	+ If SSB design is needed for 960 kHz SCS, design new SSB mapping pattern that allows beam switching gap of 100 ns and/or possible LBT gap between consecutive SSBs.
	+ Existing FR2 SSB and Type0-PDCCH multiplexing patterns are a good starting point for above 52.6 GHz operation.
	+ If SSB design is needed for 960 kHz SCS, changes would be needed to SSB and RMSI multiplexing patterns, and more specifically on the CORESET Type0-PDCCH time domain allocation to take into potentially required beam switching and/or LBT gap.
* From [31]:
	+ Study the window duration/timing granularity to search a SSB set.

**Discussion:**

From the discussions, there seems to be many consideration aspects for SSB and CORESET#0 design. Moderator thinks it would be good to narrow down list of issues (or if possible, agree on some principles or issues). We may try to capture the potential issues or guiding principles into the TR once stabilized.

Please comment further on the following:

* Consider the following aspects for SSB and CORESET#0 design for a given SCS
	+ Whether re-use of existing SSB and/or SSB and CORESET multiplexing pattern is possible (assuming the SSB SCS and/or COREST SCS is something that is already supported in existing NR)
	+ Beam switching gap for signal(s)/channel(s)
	+ Time granularity of placement of SSB
	+ Multiplexing of system information (e.g. RMSI, SIB1) with SSB
	+ Multiplexing of PDCCH (for system information, and possible others) with SSB
	+ Number of transmission opportunities within a transmission window (such as DRS window)
	+ Supported multiplexing pattern type (either 0, 1, or 2) for SSB and CORESET#0 multiplexing.

Please comment on whether you think above is something useful to capture. If companies have some different suggestion regarding SSB and CORESET design aspects, please provide comments. Also, if there are (sub-)bullet that is missing or needs correction, please comment as well.

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| **Company** | **Comments** |
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## 3.4 SSB numerology

The following are observations/proposals specifically related to SSB numerology from the submitted contribution.

### 3.4.1 General aspects on SSB numerology

* From [4]:
	+ SSB numerology would better to be determined after BWP numerology is selected and supported (SSB, corset 0) numerology pairs need to be determined as well by considering koffset indication and SSB-Coreset 0 multiplexing pattern.
* From [15]:
	+ There are several sources of frequency errors, e.g. inter-gNB frequency accuracy, UE initial frequency accuracy, UE frequency drift and Doppler shift, all which scales with the carrier frequency.
	+ Thus, to keep the ratio ∆f/SCS similar at different carrier frequencies, the SCS needs to scale accordingly.
	+ From a frequency error perspective, an SSB SCS of either 240 kHz or 480 kHz seems reasonable for a 60 GHz carrier frequency.
	+ A higher UL SCS puts tighter requirements on UE UL timing accuracy.
	+ To avoid further tightening the UE requirement on UL timing error in relation to 1/SCSSSB compared to current specifications, the UL SCS should not be more than twice that of the SSB SCS.
	+ This motivates selection of UL SCS to be no greater than 480 kHz assuming the maximum SSB SCS of 240 kHz in the spec today.
	+ Extended CP need not be considered for NR operation in 52.6 to 71 GHz.
* From [16]:
	+ consider reusing FR2 SCS for initial access phase
* From [29]:
	+ Regarding SSB numerologies:
		- Support existing SSB numerologies and
		- study further need for new numerologies for SSB and Type0-PDCCH design.

### 3.4.2 Cell Search Complexity

* From [4]:
	+ frequency domain offset estimation during SSB detection. With increasing of the center frequency, the absolute value for frequency domain offset is increased if assuming the same ratio (e.g. 10ppm).
	+ The following aspects should be studied for SSB design: (1) Frequency domain offset estimation; (2) Amount of buffering SSB samples; (3) Beam switching for contiguous candidate SSBs.

### 3.4.3 Discussion

From the discussions, there seems to be some additional/different aspects to consider for SSB subcarrier spacing, which may or may not be same as other data channels.

Please comment further on the following:

* Consider the following aspects for determination of supported SSB subcarrier spacing
	+ Detection performance of SSB (including PSS, SSS, PBCH DMRS, and PBCH)
	+ Consideration of multiplexing with regular data subcarrier spacing (i.e. BWP subcarrier spacing)
	+ Initial cell search complexity from relative increase of frequency errors (e.g. carrier frequency offset, Doppler shift, etc)
	+ Timing detection accuracy and its relation to uplink transmission accuracy
	+ Signaling design for supporting different subcarrier spacing for SSB and CORESET#0 (if supported)

Please comment on whether you think above is something useful to capture. If companies have some different suggestion regarding SSB numerology, please provide comments. Also, if there are (sub-)bullet that is missing or needs correction, please comment as well.

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| **Company** | **Comments** |
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## 3.8 PRACH

The following are observations/proposals specifically related to PRACH design from the submitted contribution.

* From [2]:
	+ For unlicensed band, new ZC lengths should be considered (for OCB).
* From [4]:
	+ Format 0-3 with special SCS is not supported and the candidate PRACH numerologies for format A, B and C are the same as the candidate BWP numerologies. Both coverage and capacity should be studied for PRACH design with new defined numerology.
* From [14]:
	+ When a large subcarrier spacing is defined, PRACH configuration related aspects need to be investigated.
* From [17]:
	+ RAN1 shall study the scaling/reuse of current PRACH SCS with some enhancement including the non-consecutive RO configuration.
* From [25]:
	+ For PRACH sequence, short PRACH sequence supported in Rel-15 NR should be a baseline
* From [29]:
	+ Introducing longer sequence lengths for short time domain PRACH preambles, e.g. the ones supported in Rel-16 NR-U (571 and 1151), would allow transmitting device to achieve 40 dBm EIRP maximum in CEPT scenarios c1 and c2.

**Discussion:**

There were several discussions, on PRACH especially on its length and supported coverages.

Please comment further on the following:

* Consider the following aspects for PRACH design
	+ Sequence lengths (possibly other than what is supported in Rel-15 and 16 NR) for 60 GHz unlicensed operation
	+ RACH RO configurations with new SCS (if new SCS is supported)

Please comment on whether you think above is something useful to capture. If companies have some different suggestion regarding PRACH design aspects, please provide comments. Also, if there are (sub-)bullet that is missing or needs correction, please comment as well.

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| **Company** | **Comments** |
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## 3.9 PT-RS

The following are observations/proposals specifically related to PT-RS design and phase noise compensation from the submitted contribution.

* From [1]:
	+ For supporting NR operation between 52.6GHz and 71GHz in Rel. 17, no PT-RS configuration should also be supported, depending up on the MCS range, if higher subcarrier spacing values are agreed to be supported.
* From [2]:
	+ Block PTRS enables low complexity ICI compensation for smaller SCSs such as 120 kHz and 240 kHz and helps the smaller SCS to perform even better than a larger SCS such as 960 kHz.
* From [4]:
	+ DM-RS/PT-RS enhancement should be studied to solve the problem brought by RF impairment such as phase noise, I-Q imbalance and PA non-linear work range.
* From [8]:
	+ Methods to eliminate ICI induced by phase noise should be studied for NR operation in the 60 GHz band.
* From [13]:
	+ Investigate PT-RS patterns allowing for ICI compensation for CP-OFDM. Support block-based PTRS patterns for OFDM waveform. Support density extension of current Rel.15 PTRS for DFTsOFDM waveform.
* From [16]:
	+ further study the need for PTRS enhancement for smaller SCS than 960KHz
* From [17]:
	+ RAN1 shall study the enhancement to reference signals (e.g. PT-RS) for the new carrier frequency range, taking into consideration of the impact from the new numerology.
* From [22]:
	+ RAN1 to study the need to update Rel-15 PTRS for both OFDM and DFT-S-OFDM to account increased CPE/ICI at higher frequencies.
* From [23]:
	+ The spectral efficiency (include guard band, PT-RS overhead, etc.) for large number of carrier aggregation should be studied for NR operation from 52.6 to 71 GHz.
* From [25]:
	+ How to allocate resource for RS (e.g. DMRS, PTRS) in frequency domain needs to be considered for higher SCS if introduced
* From [29]:
	+ Consider block-PTRS for CP-OFDM. Consider defining new PTRS configurations for DFT-s-OFDM.

**Discussion:**

PT-RS is very integral to the phase noise compensation and overall performance for NR operating in the 60 GHz band. Several companies has brought information on new potential method to process with PT-RS for inter-carrier interference (ICI) other than common phase error (CPE) compensation, or new PT-RS design that potentially help with ICI from phase noise. Other several companies has commented about density and configurations based on existing PT-RS design.

Please comment further on the following:

* Consider the following aspects PT-RS design for a given SCS
	+ CPE and ICI compensation performance of existing PT-RS design
	+ Study of need of any modification/changes to existing PT-RS design
	+ Potential modification to the PT-RS pattern or configuration to aid performance improvement for CP-OFDM and DFT-s-OFDM waveforms.
	+ Potential methods to aid ICI compensation at the receiver

Please comment on whether you think above is something useful to capture. If companies have some different suggestion regarding PT-RS design aspects, please provide comments. Also, if there are (sub-)bullet that is missing or needs correction, please comment as well.

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| **Company** | **Comments** |
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## 3.10 DM-RS

The following are observations/proposals specifically related to DM-RS design from the submitted contribution.

* From [1]:
	+ For higher SCS values with both 400MHz and 2GHz bandwidth, BLER performance difference between the ideal channel estimation and real channel estimation varies for different SCS values, where, as the subcarrier spacing is increasing, the performance degradation with real channel estimation also increases which could be attributed to the performance of DM-RS configuration with different SCS values.
	+ For supporting NR beyond 52.6 GHz with existing waveforms in Rel. 17, if higher subcarrier spacings (numerologies) are adopted, new DM-RS configurations should be studied.
* From [20]:
	+ Investigate the necessity to enhance the structure of DM-RS for data as well as control DL/UL channels.
* From [21]:
	+ Study enhanced DM-RS designs for a larger subcarrier spacing for PDSCH and PUSCH. Study channel estimation performance impact of PDCCH and PUCCH with a larger subcarrier spacing.
* From [25]:
	+ How to allocate resource for RS (e.g. DMRS, PTRS) in frequency domain needs to be considered for higher SCS if introduced. DMRS density in frequency domain may not be sufficient. DMRS ports multiplexing may not work well
* From [31]:
	+ Study enhancement of the frequency domain structure of DMRS for NR on 52.6 GHz to 71 GHz.

**Discussion:**

Some companies have mentioned potential challenges with existing DM-RS, when scaled to higher subcarrier spacings.

Please comment further on the following:

* Consider the following aspects DM-RS design for a given SCS
	+ Validate any issues for current DM-RS design supported in Rel-15/16 NR.
	+ Study any potential enhancements for DM-RS for various channels (if needed)

Please comment on whether you think above is something useful to capture. If companies have some different suggestion regarding DM-RS design aspects, please provide comments. Also, if there are (sub-)bullet that is missing or needs correction, please comment as well.

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| **Company** | **Comments** |
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## 3.11 Processing Timelines

The following are observations/proposals specifically related to processing timelines for various signals and channels from the submitted contributions.

### 3.11.1 Processing Timelines - General

* From [3]:
	+ If numerologies higher than 120 kHz are introduced, the processing timelines (BWP switching times, HARQ scheduling, UE processing, preparation and computation times for PDSCH, PUSCH/SRS and CSI) and PDCCH monitoring capability should be studied for the new numerologies.
* From [4]:
	+ Timeline definition, basic time unit and super long CP per half frame should be discussed for new defined numerology such as (960K, NCP).
* From [7]:
	+ If introducing new numerology, the impacts on processing time and scheduling operation should be considered.
* From [10]:
	+ For PDSCH/PUSCH processing, N1/N2 values for µ larger than 3 should be defined with consideration of different UE processing capabilities.
	+ For PDSCH to HARQ-ACK timing, the value range of k1 should be extended to facilitate SCS higher than 120kHz. UL grant to PUSCH timing, the value range of k2 should be extended to facilitate SCS higher than 120kHz.
	+ UE processing capability for PDSCH/PUSCH should be defined for SCS higher than 120kHz.
	+ Multiple slot-based UE processing capability for PDCCH blind decoding for should be defined for µ larger than 3.
* From [11]:
	+ Determine the processing time when the new numerologies are decided. Study the range of K0, K1, K2 for the new SCS.
* From [14]:
	+ When a large subcarrier spacing is defined, processing time related aspects, including PDSCH/PUSCH processing time, CSI computation time, etc., need to be investigated.
* From [15]:
	+ UE processing timelines for SCS > 120 kHz need to be further tightened vis-à-vis those for 120 kHz SCS to enable high performance NR operation in 52.6 to 71 GHz.
	+ The times provisioned for UE processing grow exponentially with the numerology.
	+ Large processing latencies restrict the achievable throughputs, defeating the purpose of enabling large bandwidths with large sub-carrier spacings.
	+ RAN1 should investigate the different factors that contribute to the PDSCH processing time and consider possible latency reduction opportunities.
* From [17]:
	+ RAN1 shall study the processing timing related procedures for modification/enhancement, taking into consideration of the impact from the new numerology.
	+ Timing indication (K0/K1/K2); HARQ procedure with increased value of K0/K1/K2; PDCCH monitoring with practical PDCCH BD capability; Multi-PDSCH/PUSCH scheduling
* From [20]:
	+ It would be beneficial in terms of UE implementation complexity or power consumption to perform slot(or symbol)-group level processing instead of every slot(or symbol) processing, e.g. PDCCH monitoring and CSI processing unit availability check.
* From [21]:
	+ Study required UE processing time and switching time for larger subcarrier spacings to be introduced. Study enhanced processing time determination methods to reduce the redundant processing time.
* From [22]:
	+ RAN1 to modify the UE timing parameter values and their associated signaling.
* From [25]:
	+ For higher SCS, the appropriate configuration of k0, k1, k2 need to be discussed to meet UE minimum processing timeline.
	+ If the current candidate values don’t meet UE processing limitation, extending, limiting or shifting the range of k0, k1, k2 may be necessary

### 3.11.2 Processing Timelines – CSI Specific

* From [1]:
	+ For supporting NR beyond 52.6 GHz with existing waveforms in Rel. 17, if higher subcarrier spacings (numerologies) are adopted, then potential enhancements should be considered on how to efficiently utilize UE’s limited processing capability to reduce latency and efficiently handle processing/preparation of CSI reports associated with multiple numerologies parallelly.
* From [10]:
	+ For CSI computation, Z1/Z2/Z3 value for µ larger than 3 should be defined with consideration of different CSI computation delay requirements.

### 3.11.3 Discussion

Please comment further on the following:

* Consider the following aspects processing timelines for given SCS
	+ For new SCS not supported in existing NR specification, study the following aspects
		- appropriate configuration(s) of k0, k1, k2,
		- PDSCH processing time,
		- PUSCH preparation time,
		- CSI processing time, Z1, Z2, and Z3
		- [BWP switching time] – RAN4?
		- Related UE capability(ies) for processing timelines

Please comment on whether you think above is something useful to capture. If companies have some different suggestion regarding processing timeline design aspects, please provide comments. Also, if there are (sub-)bullet that is missing or needs correction, please comment as well.

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| **Company** | **Comments** |
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## 3.12 PDCCH Monitoring

The following are observations/proposals specifically related to PDCCH monitoring from the submitted contributions.

* From [1]:
	+ For supporting NR beyond 52.6 GHz with existing waveforms in Rel. 17, if higher subcarrier spacings (numerologies) are adopted, then the PDCCH monitoring capability would be further reduced and the number of PDCCH candidates per slot would be lower.
	+ For supporting NR beyond 52.6 GHz with existing waveforms in Rel. 17, if higher subcarrier spacings (numerologies) are adopted, then the PDCCH processing in every slot might not be scalable with increasing subcarrier spacing, due to limitations with UE processing capability.
	+ For supporting NR beyond 52.6 GHz with existing waveforms in Rel. 17, if higher subcarrier spacings (numerologies) are adopted, then enhancements to current PDCCH design including the possibility:
		- To introduce new DCI formats should be considered for reduced PDCCH monitoring and efficient scheduling for both UL and DL,
		- To limit the monitoring to specific DCI formats
* From [14]:
	+ When a large subcarrier spacing is defined, maximum number of BDs/CCEs for PDCCH monitoring needs to be investigated.
* From [22]:
	+ Study mechanisms to limit the increase in PDCCH monitoring complexity with any change in the SCS
* From [29]:
	+ Increase of the minimum scheduling/ PDCCH monitoring unit to avoid excessive increase in PDCCH monitoring rate.
	+ Support Multi-PDSCH DCI for reaching peak data-rates for the cases of high SCSs.
	+ Determine BD/CCE limits based on nominal scheduling/monitoring unit such as slot of e.g. 120kHz (defined in R15)/240kHz (FFS).

**Discussion:**

Many companies have noted that based on existing specification the PDCCH monitoring support by the UE should shrink as subcarrier spacing grows. Study of the exact PDCCH monitoring support by the UE and related issues need further investigation.

Please comment further on the following:

* Consider the following aspects PDCCH monitoring for a given SCS
	+ For new SCS not supported in Rel-15/16 NR,
		- investigate on the maximum number of BDs/CCEs for PDCCH monitoring
		- any potential limitation to PDCCH monitoring configurations (e.g. search spaces, DCI formats, etc) to help with UE processing (if needed)

Please comment on whether you think above is something useful to capture. If companies have some different suggestion regarding PDCCH monitroing aspects, please provide comments. Also, if there are (sub-)bullet that is missing or needs correction, please comment as well.

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| **Company** | **Comments** |
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## 3.13 Scheduling and DCI Formats

The following are observations/proposals specifically related to DCI formats and related scheduling operations from the submitted contributions.

* From [14]:
	+ When a large subcarrier spacing is defined, multi-TTI based scheduling can be considered to relax scheduler implementation and higher layer processing burden
* From [15]:
	+ For 60GHz operation, reduce the FDRA fields size by supporting larger RBG sizes
	+ Consider a gNB initiated polling approach for UL traffic management to reduce UL data latency
	+ Consider support of scheduling multiple PDSCH using one DCI for NR operation in 52.6 to 71 GHz
* From [17]:
	+ RAN1 shall study more flexible resource allocation in both time and frequency domain for different scenarios, including slot bundling, subcarrier bundling/sub-PRB.
* From [25]:
	+ The current granularity in time/frequency domain in Rel-15/16 may be too fine, assuming less opportunity for FDM between UEs due to narrower beam width and larger number of symbols required for coverage performance.
	+ How to allocate resource for data in frequency domain needs to be considered especially for higher SCS if introduced. PDSCH/PUSCH allocated on more than 14 symbols would be beneficial.

**Discussion:**

Few companies have mentioned that some updates to time and/or frequency domain scheduling may be needed for large subcarrier spacing due to shorter slot durations. Additionally, extensive use of beams in the 60 GHz band may limit the frequency domain multiplexing possible.

Please comment further on the following:

* Consider the following aspects scheduling for BWP with a given SCS
	+ Study of frequency domain scheduling enhancements/optimization
	+ Study of time domain scheduling enhancements

Please comment on whether you think above is something useful to capture. If companies have some different suggestion regarding scheduling aspects, please provide comments. Also, if there are (sub-)bullet that is missing or needs correction, please comment as well.

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## 3.14 UL specific aspects

The following are observations/proposals specifically related to uplink channel design from the submitted contributions.

### 3.14.1 PUCCH

* From [15]:
	+ PUCCH format 0/1/4 enhancements to compensate for the limited transmit power should be studied. Consider enhancements to SR (PUCCH) resource configuration and spatial relation management to reduce UL data latency
* From [26]:
	+ In addition to the design issues discussed in RAN1 #101-e, discuss the design of PUCCH to achieve higher EIRP up to maximum allowed EIRP.
* From [29]:
	+ Consider support for contiguous multi-PRB allocation for PUCCH format 0 and format 1 or use of PUCCH format 2 and format 3 for SR and before dedicated PUCCH configuration.

### 3.14.2 UL Interlace Transmission

* From [1]:
	+ For supporting NR beyond 52.6 GHz in unlicensed band in Rel. 17, study the enhancement of PRB/sub-PRB interlacing designs for NR with higher SCS, if agreed to be supported.
* From [2]:
	+ PRB based interlace resource mapping for PUSCH/PUCCH/SRS should be studied in NR-U-60.
	+ More evaluation is required before introducing PRB-based interlacing in NR-U-60.
* From [5]:
	+ Similar as NR-U in Rel-16, to maximize transmission power under regulation requirements, interlaced structure should be supported for the SCS and bandwidth of the unlicensed spectrum between 52.6 GHz and 71 GHz.
* From [12]:
	+ RAN1 shall study high BW formats, up to 2.16 GHz, for NR-U PUCCH in 60 GHz band. RAN1 shall study the possibility to assign NR-U PUCCH onto partial interlaces for high BW channels.
* From [15]:
	+ PRB-based interlacing is not beneficial for SCS ≥ 120 kHz. Sub-PRB interlacing is not beneficial for SCS ≥ 960 kHz.
	+ Both PRB and sub-PRB interlacing is not beneficial for large frequency allocations.
	+ The support of UL interlace allocation is not considered for operation in >52.6 GHz spectrum
	+ To fulfil the OCB requirement specified in EN 302 567, for each of the declared channel bandwidths, the device has to support at least one mode of transmission where the transmission occupies at least 70% of the declared channel bandwidth.
	+ Existing NR design fulfills the EN 302 567 OCB requirement
* From [20]:
	+ Design wide-band PRACH and interlaced PUSCH/PUCCH considering regulatory requirements such as nominal channel BW, occupied channel BW, maximum allowed output power, and maximum power spectral density.
* From [25]:
	+ In unlicensed band, interlaced PUCCH/PUSCH would be necessary.
* From [27]:
	+ In order to meet the requirements of minimum OCB, some enhancement on interlace design with unregular RB number might be considered.
* From [29]:
	+ No interlaced transmission is defined for 60 GHz unlicenced band.

### 3.14.3 Discussion

Please comment further on the following:

* Consider the following aspects for uplink transmission
	+ Study of potential enhancements for PUCCH/PRACH transmissions to achieve higher transmit power (when transmit power spectral density limits apply)
	+ Study of potential enhancements uplink interlace design for PUCCH/PUSCH including on whether uplink interlace needs to be supported at all for unlicensed operation in 60 GHz band.

Please comment on whether you think above is something useful to capture. If companies have some different suggestion regarding uplink transmission aspects, please provide comments. Also, if there are (sub-)bullet that is missing or needs correction, please comment as well.

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## 3.15 Multi-Carrier Operations

The following are observations/proposals specifically related to multi-carrier operations from the submitted contributions.

* From [6]:
	+ Silicon footprint for having large single FFT (using one CC) and multiple smaller FFT (using CA) could be compariable
* From [20]:
	+ Consider carrier-group based operation for NR unlicensed band in frequency range above 52.6 GHz, with consideration of multi-RAT coexistence as well as control signalling efficiency.
* From [23]:
	+ The signal overhead for scheduling large number of aggregated carriers should be studied for NR operation from 52.6 to 71 GHz.
* From [29]:
	+ Support both channel bonding and CA between 2.16 GHz channels
* From [31]:
	+ Study whether/how to utilize wide available spectrum such as more than 10 GHz bandwidth in 52.6-71GHz frequency range.

**Discussion:**

Several companies mentioned that CA could be utilized to support larger aggregate bandwidth. Companies also mentioned that control signaling efficiency and transceiver complexity for single carrier with large bandwidth versus multiple carrier with smaller bandwidth needs to be factored into account.

Please comment further on the following:

* Consider the following aspects multi-carrier operation
	+ Study of multi-carrier operation to facilitate larger aggregate bandwidths (e.g. 2.16 GHz or larger)
	+ Study of control signaling efficiency, transceiver complexity, and multi-RAT coexistence when multi-carrier operation is utilized compared to a single wideband carrier.

Please comment on whether you think above is something useful to capture. If companies have some different suggestion regarding multi-carrier operations aspects, please provide comments. Also, if there are (sub-)bullet that is missing or needs correction, please comment as well.

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## 3.16 Beam related issues/aspects

The following are observations/proposals specifically related to beam operations from the submitted contributions.

### 3.16.1 Beam Switching

* From [25]:
	+ sufficient time gap for beam switching between transmissions/receptions with different beam directions may be necessary in case of high SCS.
* From [29]:
	+ Study the impacts of beam switching gap on NR physical layer design extended to higher SCSs. The following assumptions are taken when considering need for the explicit beam switching gap:
		- Max 100 ns assumed as beam switching time;
		- If the CP is longer than 100 ns, no explicit gap is needed for the beam switching

### 3.16.2 Beam Management

* From [2]:
	+ Study the use of aperiodic CSI-RS for BFR procedure in NR-U-60.
* From [17]:
	+ RAN1 shall study the beam adjustment mechanism in initial access procedure.
* From [20]:
	+ Study potential enhancements for beam management CSI-RS or SRS considering beam switching time and coverage loss for large SCS.
* From [25]:
	+ SSB beam may not be narrow enough considering large propagation loss. In order to improve the coverage performance of DL transmissions following SSB during initial access, beam refinement during initial access may be beneficial.
	+ BFR procedure enhancement needs to be considered with at least following points:
		- The number of candidate beams included in set q1;
		- The minimum time gap to apply new beam configuration after receiving BFR response from gNB; Simultaneous update of beam configuration for multiple SCells;
		- Monitoring aperiodic transmissions for beam failure detection
* From [29]:
	+ For P-TRS transmissions in the cell, it would be beneficial to have a mechanism to be able to transmit P-TRSs dropped due to LBT failure.
	+ Applied coexistence mechanism(s) should be clarified before impact on beam management and the CSI measurement and reporting framework can be fully evaluated.
	+ As the UE moves in a cell, the likelihood of blockage and beam mis-alignment increases with decreasing beamwidths used by the gNB.
	+ Connectivity and robustness improvements are being developed for FR2 in the MIMO WID under multi-beam enhancements and multi-TRP agenda items, and those improvements are also expected to be valid solutions above 52.6 GHz operation.

### 3.16.3 Discussion

Several companies mentioned aspects related to beam management and beam transition aspects.

Please comment further on the following:

* Consider the following aspects beam management
	+ Study the use of aperiodic CSI-RS for BFR
	+ study the beam adjustment mechanism in initial access procedure
	+ study of beam refinement during initial access
	+ study of a mechanism to transmission P-TRSs potentially dropped due to LBT failure
* Consider study of handling of beam switching gap for higher subcarriers spacing (if supported)

Please comment on whether you think above is something useful to capture. If companies have some different suggestion regarding beam management design aspects, please provide comments. Also, if there are (sub-)bullet that is missing or needs correction, please comment as well.

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## 3.17 Other Issues/Aspects

The following are pool of issues that was mentioned by few companies. It should be noted that issues categorized under this section does not imply the issue is less important or otherwise. The issues were categorized under this section because each issue was discussed by only few companies.

### 3.17.1 TDD Transition Time

* From [3]:
	+ A larger fraction of a slot is used for switching between Tx and Rx with higher numerology, which is 7µs.
	+ For 240 kHz SCS, 2 symbols would be needed for transition, 4 symbols are needed for 480 kHz SCS, and 7 symbols are needed for 960 kHz SCS. This additional overhead should be accounted.

### 3.17.2 Cell Coverage

* From [2]:
	+ 60 kHz SCS (support up to 2500m), 120 kHz SCS (support up to 1250m), 240 kHz SCS (support up to 625m), 480 kHz SCS (support up to 313m), 960 kHz SCS (support up to 156m)
	+ 60 kHz SCS can support a coverage close to the maximum expected coverage for the backhauling use cases while increasing the SCS of preamble will reduce the coverage and the maximum cell radius.
* From [4]:
	+ Coverage enhancement mechanism should be studied for PDCCH design especially for high SCS.
* From [29]:
	+ Support improved PDCCH coverage for the cases of high SCS
	+ Consider coverage enhancements for channels and signals with higher SCS.

### 3.17.3 Transmission Rank

* From [29]:
	+ Consider supporting rank-2 SU-MIMO for DFT-s-OFDM.

### 3.17.4 Channelization

* From [7]:
	+ When determining supported bandwidths for NR above 52.6 GHz, RAN1 should take co-existence of IEEE 802.11ad/ay into account at least in unlicensed band.
	+ In licensed frequency band or in a controlled environment, it can be designed in a unified way with unlicensed band or independently.
	+ 400 MHz (and/or its integral multiple e.g. 800/1600 MHz) and 2.16 GHz can be served as candidates of supported bandwidths for Rel-17 NR above 52.6 GHz.
* From [29]:
	+ Support operation with CBW=2.16 GHz

### 3.17.5 MAC Buffering

* From [15]:
	+ Very larger sub-carrier spacing will induce excessive MAC buffering requirements and causes higher UE implementation costs.

### 3.17.6 HARQ Processes

* From [15]:
	+ Because of larger processing latencies, the numbers of DL and UL HARQ processes may need to be increased.
	+ Otherwise, physical layer specification and implementation changes compared to Rel-15 may be needed to sustain high data throughput.
* From [22]:
	+ RAN1 to modify the design of the HARQ feedback mechanism to accommodate timeline changes from the increased number of slots due to a possible increase in the SCS.

### 3.17.7 Additional RF Impairments

* From [4]:
	+ Perform modeling of I/Q imbalance in link level evaluation with reasonable sideband suppression value, and study potential enhancement if problem is identified.
	+ Perform PAPR evaluation for different channels/signals, and study potential PAPR reduction technique if problem is identified.

### 3.17.8 Discussion

For issues that were provided by few companies, moderator has put all of them to the other issues and aspects. Please note, this does not mean these issues are less important. Moderator has try to summarize all the mentioned aspects below.

Please comment further on the following:

* Consider the study of the following aspects
	+ System overhead impact from TDD switching time for larger subcarrier spacing
	+ Coverage enhancement mechanisms for control channels
	+ Any potential modifications to HARQ processes including number of processes that should be supported
	+ Impact from MAC buffering for larger subcarrier spacing
	+ Channelization and impact from potential alignment or misalignment with 11ad channels
	+ Support of rank 2 transmission for DFT-s-OFDM in the uplink
	+ Additional RF impairments that impact evaluations

Please comment on whether you think above is something useful to capture. If companies have some different suggestion regarding mentioned study aspects, please provide comments. Also, if there are (sub-)bullet that is missing or needs correction, please comment as well.

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| **Company** | **Comments** |
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