**3GPP TSG RAN WG1 Meeting #104-e R1-210yyyy**

**E-meeting, January 25th – February 5th, 2021**

**Source: Moderator (vivo)**

**Title: Discussion summary #1 of [104-e-NR-52-71GHz-05]**

**Agenda item: 8.2.5**

**Document for: Discussion and decision**

# Introduction

In this contribution, we summarize issues regarding PDSCH/PUSCH enhancements for new SCSs on supporting NR from 52.6 GHz to 71 GHz for the following email discussion in RAN1 #104-e.

[104-e-NR-52-71GHz-05] Email discussion/approval on defining maximum bandwidth for new SCSs, timeline related aspects adapted to each of the new numerologies 480kHz and 960kHz and reference signals with checkpoints for agreements on Jan-28, Feb-02, Feb-05 – Huaming (Vivo)

Note that the scope of agenda 8.2.5 including defining maximum bandwidth for new SCSs, time line related aspects adapted to each of the new numerologies 480kHz and 960kHz, reference signals, scheduling particularly w.r.t. multi-PDSCH/PUSCH with a single DCI, HARQ, etc. In this summary, only issues related to bandwidth for new SCSs, time line related aspects adapted to each of the new numerologies 480kHz and 960kHz and reference signals are summarized. Issues related to scheduling particularly w.r.t. multi-PDSCH/PUSCH with a single DCI, HARQ are not in the scope of this summary.

# PDSCH/PUSCH enhancements for new SCSs

In this section, we provide a summary of issues, observations and proposals related to PDSCH/PUSCH enhancements for new SCSs discussed in the submitted contributions.

As in WID, the related objectives for this summary of agenda 8.2.5 are the following.

* Physical layer aspects including [RAN1]:
  + In addition to 120kHz SCS, specify new SCS, 480kHz and 960kHz, and define maximum bandwidth(s), for operation in this frequency range for data and control channels and reference signals, only NCP supported.

Note: Except for timing line related aspects, a common design framework shall be adopted for 480kHz to 960kHz

* + Time line related aspects adapted to 480kHz and 960kHz, e.g., BWP and beam switching timing, HARQ timing, UE processing, preparation and computation timelines for PDSCH, PUSCH/SRS and CSI, respectively.
  + Evaluate, and if needed, specify the PTRS enhancement for 120kHz SCS, 480kHz SCS and/or 960kHz SCS, as well as DMRS enhancement for 480kHz SCS and/or 960kHz SCS.

## 2.1. Maximum and minimum channel bandwidth(s)

### Individual observations/proposals

The following are individual observations/proposals from the contributions.

|  |  |
| --- | --- |
| Sources | Observations/proposals |
| [3, ZTE] | Observation 1: Aligned and misaligned channelization show similar performance in coexistence scenario.  Proposal 1: The following options are proposed for channelization for Rel-17 NR beyond 52.6 GHz, wherein Option 2 is preferred.   * Option 1: Align the channelization of Rel-17 NR with Wi-Fi design at least in unlicensed band (e.g. 57 GHz - 71 GHz) * Option 1-1: Support a basic unit of 2.16 GHz channel bandwidth * Option 1-2: Divide X of 400 MHz, Y of 800 MHz and Z of 1600 MHz per 2.16 GHz bandwidth. Where X = 0 to 5, Y = 0 to 2, and Z = 0 to 1. * In other licensed frequency band (e.g. 52.6 GHz - 57 GHz) or in a controlled environment without Wi-Fi devices, it can be designed uniformly with unlicensed band or independently * Option 2: No need to align the channelization of Rel-17 NR with Wi-Fi design even in unlicensed band. Support the same bandwidth(s) (e.g. 400/800/1600 MHz) in licensed and unlicensed frequency bands * Option 2-1: Support a nominal channel bandwidth of 2.16 GHz by the aggregation of above basic bandwidth(s) (e.g. 400/800/1600MHz) * Option 2-2: No need to support a nominal channel bandwidth of 2.16 GHz   Proposal 2: The maximum channel bandwidth for the new SCSs 480/960 kHz can be defined as 1600 MHz. |
| [5, Huawei] | Proposal 2: For NR operating in 52.6-71 GHz, the supported minimum carrier bandwidth is 200 MHz for 120 kHz and 480 kHz SCS. The minimum carrier bandwidth is 400 MHz with 960 kHz SCS.  Proposal 3: The maximum carrier bandwidth depends on the subcarrier spacing:  • 400 MHz for 120 kHz SCS  • 1600 MHz for 480 kHz SCS  • FFS for 960 kHz SCS, e.g. 3200, 2400 or 2000 MHz (ask RAN4) |
| [6, Nokia] | Proposal 1: For operation without CA, support the following CBWs: 400 MHz (120 kHz), 1600 MHz (480 kHz) and 2.16 GHz (960 kHz).  Observation 1: Maximum BW for 480 kHz SCS, limited by the number of RBs per carrier, is 1.6 GHz.  Observation 2: With 960 kHz SCS, the maximum bandwidth is limited by the sampling rate. Increased sampling rate allows to increase the peak data rate and spectrum efficiency by up-to 6% with 2.16 GHz CBW  Observation 3: There are two options available for 960 kHz SCS  • Option 1: Don’t support higher sampling rate. Maximum number of PRBs with 960 kHz SCS is 170.  • Option 2: Support a higher sampling rate. Maximum number of PRBs is (e.g.) 178 or 180. |
| [7, CAICT] | Proposal 1: The maximum bandwidth for 480 and 960kHz SCS could consider the impact of LBT bandwidth. |
| [8, CATT] | Proposal 1: The maximum system bandwidth should be supported up to 1.6 GHz. The system analysis of supporting more than 1.6 GHz system BW should be supported with the condition of not changing of the value of Tc. |
| [9, vivo] | Proposal 1: Define the maximum supportive carrier/BWP bandwidths with different numerologies as Table 1, i.e. BW of 400 MHz for SCS of 120 KHz, BW of 1.6 GHz for SCS of 480 KHz, and BW of 2GHz for SCS of 960 KHz.  Proposal 9: The basic time unit should be re-defined for 960KHz when operation from 52.6-71GHz and its spec impact should be studied. |
| [12, Intel] | Proposal 1   * Minimum supported bandwidth of 400 MHz for any SCS. * Maximum supported bandwidth of 1600 MHz for 480 kHz SCS. * Maximum supported bandwidth of 2000 MHz for 960 kHz SCS.   + 2000 MHz could be supported without changes to Tc = 1/(480e3 \* 4096) even for 960 kHz.   + For 960kHz, up to 170 PRB can be supported without changing Tc. This results 1.9584 GHz which should be sufficiently large enough occupied bandwidth for 2GHz channel. Most likely the actual occupied channel defined by RAN4 will be smaller than 170 PRB. * The maximum number of PRB that RAN1 considers for 480kHz is 275, and 960kHz is 170. Up to RAN4 to define the exact PRB sizes for each channel bandwidth. |
| [14, Spreadtrum] | Proposal 1: Consider the maximum channel bandwidth as shown in the following table for the respective numerologies.   |  |  | | --- | --- | | Subcarrier spacing (numerology μ) | Maximum CC BW size assuming 4096 FFT size | | 120 kHz (μ = 3) | 400MHz | | 480 kHz (μ = 5) | 1600MHz | | 960 kHz (μ = 6) | 3200MHz | |
| [15, InterDigital] | Proposal 1: Support multiples of the current NR maximum bandwidth 400 MHz up to 2 GHz in 52.6 – 71 GHz.  Proposal 2: Consider potential coexistence issues with other RATs in the spectrum of 52.6 GHz to 71 GHz with 2.16 GHz maximum bandwidth. |
| [16, Sony] | Observation 1: CA (either inter-band or intra-band) can be supported, but we prefer not to rely on CA with maximum bandwidth 400MHz per carrier to achieve 2.16GHz bandwidth.  Proposal 1: Maximum bandwidth supported using a 960 kHz SCS should be 2.16 GHz. |
| [17, LG] | Proposal #1: For 480 kHz SCS and 960 kHz SCS, 1.6 GHz and 2.16 GHz are supported as maximum bandwidth, respectively. |
| [18, NEC] | Proposal 5: For 120kHz and 240KHz, Hz. For 960kHz, Hz. |
| [20, Samsung] | Proposal 1: Support maximum channel bandwidth as approximate 2 GHz (exact value up to RAN4) and no change to T\_c is needed. |
| [21, Ericsson] | Observation 6 From a RAN1 perspective, it is feasible to define a maximum channel bandwidth in the range B = [2000 .. 2160] MHz for the case of 960 kHz SCS with FFT size 4096.  Observation 7 From a RAN1 perspective, it is feasible to define a maximum channel bandwidth B ≈ 1600 MHz for the case of 480 kHz SCS with FFT size 4096. The precise value of B depends on the desired FFT utilization and desired spectral utilization. For example, B = 1635.84 MHz achieves FFT utilization of 75% and spectral utilization ≈ 90%, similar to values achieved in FR2.  Proposal 15 Inform RAN4 that from a RAN1 perspective it is feasible to define the maximum channel bandwidth for 960 kHz SCS to be in the range B = [2000 .. 2160 MHz] and for 480 kHz SCS as B ≈ 1600 MHz, using an FFT size of 4096. The precise values of B depend at least on the desired channelization design, the desired spectral utilization value (ratio of transmission BW configuration to channel BW), and a target FFT utilization value. |
| [23, Charter] | Proposal 1: 1.6 GHz channelization is supported for both new SCSs and as the maximum supported bandwidth for 480kHz SCS.  Proposal 2: 2.16 GHz is the maximum supported bandwidth for 960kHz SCS. |
| [24, Apple] | Proposal 1: Multiple carrier bandwidths should be specified with carrier bandwidths that are multiples of about 400 MHz  Proposal 2: The maximum channel bandwidth of about 2.16 GHz should be used for co-existence with the existing 802.11ad/ay channel allocation with no overlap between a single NR channel and multiple 802.11ad/ay channels.  Proposal 3: For 120 kHz and 480 kHz, 2 GHz channel bandwidth transmission can be achieved by carrier aggregation. |
| [26, NTT DoCoMo] | Proposal 1: For maximum carrier bandwidth,   * 1.6 GHz should be supported with 480 kHz SCS * At least about 2 GHz should be supported with 960 kHz SCS   + Larger than 2.16 GHz can also be discussed further |

### Summary on bandwidth(s)

Based on the contributions, there are three sub issues discussed in the contributions, (1) maximum channel bandwidth, (2) minimum channel bandwidth, (3) channelization

#### Maximum channel bandwidth

The following options are proposed from the contributions on the maximum channel bandwidth.

Table 1 Maximum channel/carrier BW with different numerologies

|  |  |
| --- | --- |
| **Numerology** | **Maximum channel/carrier bandwidth** |
| (120 K, NCP) | 400MHz |
| (480 K, NCP) | 1600MHz: [3, ZTE], [5, Huawei], [6, Nokia], [8, CATT], [9, vivo], [12, Intel], [17, LG], [23, Charter], [26, NTT DoCoMo], (≈ 1600MHz, [21, Ericsson]) |
| (960 K, NCP) | Option 1: 1600MHz: [3, ZTE], [8, CATT]  Option 2: 2000MHz: [9, vivo], [12, Intel], [15, InterDigital], (≈ 2000MHz, [20, Samsung]), [21, Ericsson], (≈ 2000MHz, [26, NTT DoCoMo])  Option 3: 2160MHz: [6, Nokia], [16, Sony], [17, LG], [21, Ericsson], [23, Charter], (≈ 2160MHz, [24, Apple])  Option 4: 3200MHz: [14, Spreadtrum]  Option 5: FFS: [5, Huawei] |

Related to the maximum channel bandwidth for 960 kHz SCS, there’s discussion on the sampling rate/time unit Tc. Currently, Tc is defined as *Tc =*1/(Δ𝑓max ∙ *Nf*), where Δ𝑓max = 480 ∙ 103 Hz and *Nf* = 4096. Without changing Tc definition, a maximum occupied bandwidth of 1.9584 GHz can be achieved ([6, Nokia], [12, Intel], [20, Samsung]) for the maximum channel bandwidth of 2 or 2.16 GHz. On the other hand, better bandwidth utilization and/or larger channel bandwidth can be supported for 960 kHz SCS with increased sampling rate by defining another time unit only applicable for 960 kHz SCS ([6, Nokia], [9, vivo], [18, NEC]).

Moderator’s comment:

Considering the vast majority support of option 3 and 4 for the maximum channel bandwidth for 960 kHz SCS, formulate the following proposal for discussion.

##### Proposal 1-1 for discussion:

* The maximum channel bandwidth for 120 kHz SCS is 400 MHz in 52.6 GHz to 71 GHz.
* The maximum channel bandwidth for 480 kHz SCS is 1600 MHz in 52.6 GHz to 71 GHz.
* Choose one of the following options as the maximum channel bandwidth for 960 kHz SCS in 52.6 GHz to 71 GHz
  + Option 1: 2000 MHz
  + Option 2: 2160 MHz
* Choose one of the following options for Tc
  + Option a: Keep Tc unchanged for all SCSs, *Tc =*1/(Δ𝑓max ∙ *Nf*), where Δ𝑓max = 480 ∙ 103 Hz and *Nf* = 4096
  + Option b: In addition to Tc, define a new *Tc2 =*1/(Δ𝑓max2 ∙ *Nf*) and Δ𝑓max2 = 960 ∙ 103 Hz and *Nf* = 4096, applicable for 960 kHz SCS only

Companies are encouraged to provide comments especially on their preference of the above options.

|  |  |
| --- | --- |
| Company Name | Comments/Views |
| Futurewei | First two bullets: Support maximum channel bandwidth for 120kHz =400 MHz and 480kHz =1600 MHz.  For forth bullet Option a) keep Tc unchanged for all SCS.  The restriction on Tc will limit the maximum channel bandwidth correspondingly for 960 kHz SCS. (third bullet). |
| LG Electronics | We support the first two bullets, i.e., 400 MHz and 1600 MHz as maximum channel bandwidth for 120 kHz SCS and 480 kHz SCS, respectively.  For the maximum channel bandwidth of 960 kHz and Tc, we prefer Option 2 and Option a.  However, it seems that RAN1 need to coordinate these issues with RAN4 before final decision. |
|  |  |

#### Minimum channel bandwidth

In [5, Huawei], it argues that a small carrier bandwidth has the benefit of maximizing the PSD when the resources are fully utilized, and is also beneficial in spectrum blocks that cannot be exactly divided by relatively large bandwidths such as 400MHz. However, setting a small minimum bandwidth may cause an inefficient implementation due to a low FFT utilization with a small number of PRBs in case of a large SCS, but also leads to a high implementation difficulty of synchronization introduced by many synchronization raster points within the large bands available in this frequency range.

[12, Intel] argues that it is quite critical for NR operating in 60 GHz to have a clear differentiating factor compared to NR operating in FR1 or FR2. It is quite difficult to imagine a UE or gNB vendor spending millions of dollars of R&D to support NR operating with 50 or 100 MHz which is better supported by existing FR1 and FR2 deployments. With the understanding of NR operating in 60 GHz should focus on even larger bandwidth that cannot be supported by existing FR1 and FR2 deployment, it proposes to support 400 MHz as the minimum channel bandwidth for all SCSs in this frequency range.

Companies’ views are summarized in the following table.

Table 2 Minimum channel/carrier BW with different numerologies

|  |  |
| --- | --- |
| **Numerology** | **Minimum channel/carrier bandwidth** |
| (120 K, NCP) | Option 1-1: 200MHz: [5, Huawei],  Option 1-2: 400MHz: [12, Intel], |
| (480 K, NCP) | Option 2-1: 200MHz: [5, Huawei],  Option 2-2: 400MHz: [12, Intel], |
| (960 K, NCP) | 400MHz: [5, Huawei], [12, Intel], |

Moderator’s comment:

The following proposal is formulated for discussion.

##### Proposal 1-2 for discussion:

* Choose one of the following options as the minimum channel bandwidth for 120 kHz SCS in 52.6 GHz to 71 GHz
  + Option 1-1: 200 MHz
  + Option 1-2: 400 MHz
* Choose one of the following options as the minimum channel bandwidth for 480 kHz SCS in 52.6 GHz to 71 GHz
  + Option 2-1: 200 MHz
  + Option 2-2: 400 MHz
* The minimum channel bandwidth for 960 kHz SCS is 400 MHz in 52.6 GHz to 71 GHz.

Companies are encouraged to provide comments especially on their preference of the above options.

|  |  |
| --- | --- |
| Company Name | Comments/Views |
| Futurewei | While the channelization discussion belongs to RAN4, we prefer for all SCS 120kHz, 480 kHz SCS and 960kHz a min channel BW of 400 MHz for unlicensed spectrum For the licensed spectrum should be decided in RAN4. |
| LG Electronics | We don’t have strong preference on this issue but prefer minimum channel bandwidth at least larger than 50 MHz (which is the minimum channel bandwidth for FR2 below 52.6 GHz). The exact value for the minimum channel bandwidth can be discussed in RAN4. |
|  |  |

#### Channelization

There’re several issues discussed in terms of channelization.

Two sources ([15, InterDigital], [24, Apple]) propose to support multiples of 400 MHz as the carrier bandwidths up to the maximum carrier bandwidth for each SCS.

Companies have diverse views regarding whether to support of channelization that are aligned with IEEE 802.11ad and 802.11ay channelization for coexistence. Recall that alignment of channelization between a NR channel and IEEE 802.11ad and 802.11ay channel in this context refers to a NR channel that is contained within one of the channels defined for IEEE 802.11ad and 802.11ay and NR channel bandwidth does not cross over channel boundaries of IEEE 802.11ad and 802.11ay. One source ([3, ZTE]) observes that aligned and misaligned channelization show similar performance in coexistence scenario and proposed no need to align with IEEE 802.11ad/ay. Some other sources ([16, Sony], [17, LG], [23, Charter], [24, Apple]) think it’s beneficial to align NR channelization with IEEE 802.11ad and 802.11ay channelization for coexistence.

Moderator’s comment:

Detailed specification on channelization is in the scope of RAN4. Suggest to discuss the principle of channelization with more RAN1 focus. The following proposal is formulated for discussion.

##### Proposal 1-3 for discussion:

* Support multiples of the minimum channel bandwidth as the channel bandwidths up to the maximum channel bandwidth for each SCS in 52.6 GHz to 71 GHz

Companies are encouraged to provide comments and/or suggestions on channelization if any.

|  |  |
| --- | --- |
| Company Name | Comments/Views |
| Futurewei | Support moderator’s proposal. |
| LG Electronics | In principle, we are supportive of Moderator’s proposal, but this issue also falls into the category that requires coordination with RAN4. |
|  |  |

#### Other issue(s)

Please provide comments if any on any missed issue(s) about bandwidth.

|  |  |
| --- | --- |
| Company Name | Comments/Views |
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|  |  |
|  |  |

## 2.2. Timeline

### Individual observations/proposals

The following are individual observations and proposals from the contributions.

|  |  |
| --- | --- |
| Sources | Observations/proposals |
| [1, Futurewei] | Proposal 1: The new values for the *beamSwitchTiming* corresponding to SCS {480kHz and 960 kHz} use ENUMERATED {sym14, sym28, sym48, sym224, sym336} as starting point.  Proposal 2: Consider using exponential models for selected delays and timeline values as baseline for the discussions of timeline changes corresponding to SCS 480kHz and 960kHz. |
| [2, Lenovo] | Proposal 4: For supporting NR between 52.6 GHz and 71 GHz with high subcarrier spacing values including 480kHz and 960kHz, following enhancements should be supported to efficiently utilize UE’s limited processing capability to reduce latency and efficiently handle processing/preparation of CSI reports associated with multiple numerologies in parallel:  - Same reference symbols duration (possibly the shortest duration corresponding to maximum supported SCS value) could be used for checking CPU availability corresponding to different CSI reports associated with different SCS values |
| [3, ZTE] | Proposal 8: For high frequency, a new UE capability for timeline related aspects should be defined based on slot (or symbol)-group granularity.  Proposal 9: Consider the phase noise estimation and compensation time on timeline design when PTRS is configured.  Proposal 10: How to interpret k0, k1 and k2 for PUSCH/PDSCH scheduling and HARQ feedback timing indication should be discussed. |
| [5, Huawei] | Proposal 4: The absolute timelines of existing Rel-15/16 features should not be further reduced than those for 120 kHz SCS. The timeline of potential Rel-17 enhancement should be analyzed case by case as per the SCS.  Proposal 6: For multi-slot PDSCH scheduling with a single DCI for 480 kHz and 960 kHz:  • k0 indicates the gap between the slot of the scheduling DCI and the first slot of the multi-slot PDSCH scheduled by the DCI  • k1 indicates the gap between the last slot of the multi-slot PDSCH and the slot carrying the HARQ information feedback corresponding to the multi-slot PDSCH  Observation 1: The ranges of k0 and k1 defined in FR2 are not suitable for multi-PDSCH scheduling if the unit of k0 and k1 is one slot of the scheduled SCS, when the scheduled SCS is 480 kHz or 960 kHz SCS.  Proposal 7: The unit of k0 and k1 should be defined as multiple slots for multi-PDSCH scheduling for 480 kHz and 960 kHz SCS.  Proposal 8: The multi-PUSCH scheduling defined in NR-U Rel-16 can be directly extended to 52.6 GHz to 71 GHz. k2 indicates the gap between the slot of the scheduling DCI and the first slot of the multi-slot scheduled PUSCH corresponding to the DCI; The unit of k2 should be defined as multiple slots for multi-PUSCH scheduling for 480 kHz and 960 kHz. |
| [6, Nokia] | Proposal 6: Consider PDSCH processing time and PUSCH preparation time in such that the following scenario can be fulfilled:  • contiguous DL/UL transmission  • up-to 16 HARQ processes  • multi-slot scheduling with 0.125ms scheduling unit size.  Proposal 7: NR to support CSI computation delay parameter for SCS of 480kHz and 960kHz.  Observation 11: Rel-15/16 schemes for CPU can be reused for 480kHz and/or 960kHz SCS. |
| [7, CAICT] | Proposal 2: For 480 and 960kHz SCS, processing time line should be based on slot level and multiple slots level processing time line could also be considered. |
| [8, CATT] | Proposal 2: The UE processing time N1/N2 with 480KHz/960KHz SCS could not be determined before the maximum system bandwidth supported is finalized.  Proposal 3: Since the maximum system bandwidth expects to increase from 400 MHz, the UE the ranges of k0, k1, k2 values could be finalized before the supported maximum system is determined for 480 kHz and 960 kHz SCS. |
| [9, vivo] | Proposal 8: The default set of PDSCH-to-HARQ\_feedback timing indicator should be adapted to the SCS of PDSCH.  Proposal 9: The basic time unit should be re-defined for 960KHz when operation from 52.6-71GHz and its spec impact should be studied. |
| [15, InterDigital] | Proposal 7: Evaluate required UE processing time for higher frequencies considering the differences on antenna/panel structure, narrower beamwidth, BWP size and new subcarrier spacings.  Observation 9: Existing processing time determination methods are based on worst case scenarios and may require more redundant processing time for higher frequencies.  Proposal 8: Study application of different processing time requirements based on parameters which contribute UE processing time. |
| [17, LG] | Proposal #9: Consider additional UE PDSCH processing procedure time (i.e., N1 symbols) when UE is required to perform both of CPE and ICI compensation, e.g., for 120 kHz SCS and 64 QAM.  Proposal #10: Consider CSI processing timeline enhancements for better availability for CPUs for multiple CSI reports associated with different numerologies. |
| [19, Xiaomi] | Proposal 1: UE processing capability for PDSCH/PUSCH should be defined for SCS 480/960kHz to allow 1 TB of PDSCH/PUSCH per several slots.  Proposal 2: For PUSCH scheduled by RAR or by the fallback RAR, Δ value should also be considered for new SCS 480/960kHz.  Proposal 3: Specify different default K1 value sets for different SCS, and each K1 set with a maximum number of 8 values to keep the K1 bit field in DCI 1-0 unchanged.  Proposal 4: Configure different K1 value sets for different SCS, and each K1 set with a maximum number of 8 values to keep the K1 bit field in DCI 1-1/DCI 1-2 unchanged.  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. |
| [20, Samsung] | Proposal 2: RAN1 shall determine proper processing timing values for 480 and 960 KHz with the consideration of reasonable UE complexity, potential latency and impact of signal/channel/physical layer procedures.  Proposal 3: Processing time for procedures based on PDCCH reception should take into account the extra complexity/time for a UE when PDCCH Monitoring enhancement methods discussed in 8.2.3 A.I. (eg. multi-slot span PDCCH monitoring) is configured.  Proposal 4: Support SCS-specific K1/K2 by reusing existing default/configured K1/K2 plus a SCS specific offset. |
| [21, Ericsson] | Observation 1 UE PDSCH/PUSCH processing timelines for SCS > 120 kHz need to be further tightened compared to those for 120 kHz SCS to enable high performance NR operation in 52.6 to 71 GHz.  Proposal 1 RAN1 should strive to narrow down the range of UE processing latencies early in the WI phase, particularly those related PDSCH/PUSCH processing (N1, N2, N3), to enable multi-PDSCH/PUSCH design to proceed. |
| [24, Apple] | Proposal 4: Modify the UE processing timelines to account for the 480 kHz and 960 kHz SCSs. These should be discussed individually.  Proposal 5: RAN1 should prioritize the discussion of the critical processing timelines in order of (a) parameter independence (b) priority and (c) sub-agenda item dependence.  Proposal 6: investigate the need for enhancements and standardization, of the following processing timelines:  • Default PUSCH time Domain resource allocation for normal CP  • UE PDSCH reception preparation time with cross carrier scheduling with different subcarrier spacings for PDCCH and PDSCH  • SRS, PUCCH, PUSCH, PRACH cancellation with dynamic SFI  • ZP CSI Resource set activation/deactivation  • Beam Switch Timing for periodic CSI-RS + aperiodic CSI-RS  • Beam switch timing for aperiodic CSI-RS  • Aperiodic CSI-RS timing offset  • Application delay of the minimum scheduling offset restriction  • SRS triggering after DCI reception |
| [25, Qualcomm] | Proposal 10: For HARQ timing indication K1, uses the last PDSCH granted in the multi-PDSCH grant as reference slot. |
| [26, NTT DoCoMo] | Proposal 2: For existing parameters related to timeline as below, whether/how to define new values for 480/960 kHz SCS should be discussed.   * Value of N1/N2/N3/Z1/Z2/Z3/d parameters shall be defined for new SCSs for supported UE capability(-ies).   + Whether to define new timeline values for new SCSs for UE capability #1 and/or UE capability #2, or to introduce new UE capability for new SCSs * For beam related timeline parameters, value of “*timeDurationForQCL*”, “*beamSwitchTiming*/*beamSwitchTiming-r16*”, “*beamReportTiming*”, “minimum guard period between two SRS resources of an SRS resource set for antenna switching” for new SCSs for supported UE capability(-ies) should be defined. * Whether/how to consider beam switching gap (i.e., time duration needed to change the beam) should be discussed. * FFS whether to introduce a larger time gap to apply new beam configuration after receiving BFR response from gNB * For DRX switching, BWP switching, search space group switching, define values for new SCSs for supported UE capability(-ies). * For K0/K1/K2 set, consider proper K0/K1/K2 set configuration and define default values for new SCSs. |

### Summary on timeline

The following time line related aspects are captured in the TR based on the outcome of SI.

It was identified that support of the new subcarrier spacing, if agreed, will at least require investigation on the need for enhancements and standardization, of the following processing timelines:

- processing capability for PUSCH scheduled by RAR UL grant,

- dynamic SFI and SPS/CG cancellation timing,

- timeline for HARQ-ACK information in response to a SPS PDSCH release/dormancy,

- minimum time gap for wake-up and Scell dormancy indication (DCI format 2\_6),

- BWP switch delay,

- multi-beam operation timing (timeDurationForQCL, beamSwitchTiming, beam switch gap, beamReportTiming, etc.),

- timeline for multiplexing multiple UCI types,

- minimum of P\_switch for search space set group switching,

- appropriate configuration(s) of k0 (PDSCH), k1 (HARQ), k2 (PUSCH),

- PDSCH processing time (N1), PUSCH preparation time (N2), HARQ-ACK multiplexing timeline (N3),

- CSI processing time, Z1, Z2, and Z3, and CSI processing units,

- any potential enhancements to CPU occupation calculation,

- related UE capability(ies) for processing timelines,

- minimum guard period between two SRS resources of an SRS resource set for antenna switching.

Most of proposals in the contributions for this agenda are high level (i.e., talking about the principles of determining timeline rather than proposals on detailed values of some particular parameter).

#### Timeline unit/granularity

Multiple contributions ([3, ZTE], [7, CAICT], [19, Xiaomi]) proposed to define a new UE capability for timeline related aspects based on slot (or symbol)-group (multiple slot/symbol) granularity. [5, Huawei] also proposed that the unit for k0 and k1should be multi-slots for multi-PDSCH/PUSCH scheduling.

Moderator’s comment:

The UE capability of processing timeline defined may need to consider both slot and multi-slot scheduling. Whether to define a new UE capability timeline unit is for discussion. The following proposal is formulated.

##### Proposal 2-1 for discussion:

* A new UE capability for processing timeline is defined whose unit is multi-slot or multi-symbol for 52.6 GHz to 71 GHz.
  + FFS for which timeline(s)

Companies are encouraged to provide comments if any.

|  |  |
| --- | --- |
| Company Name | Comments/Views |
| Futurewei | Support moderator’s proposal. |
| LG Electronics | In principle, we support Moderator’s proposal. But, whether multi-slot (or multi-symbol) based timeline definition is needed or not should be discussed on a case-by-case basis. |
| Xiaomi | Support moderator’s proposal. |

#### Methodology

Regarding how to derive the UE processing timeline for new SCSs, several contributions have discussed different approaches.

Both [1, Futurewei] and [21, Ericsson] adopted exponential models whose parameters are obtained based on some simple formulae fitted with the existing Rel-15 processing times. The new values for new SCSs are extrapolated using the fitted formulae. Note that those models are for selected delay and timeline values.

[5, Huawei] and [24, Apple] also looked into the existing timelines and observed that the processing timelines do not always scale proportionally with SCS. Both proposed that the timeline should be analysed case by case per SCS.

In [5, Huawei], it proposed the absolute time duration for all of the timelines should not decrease further due to the implementation complexity to support 120 kHz and one or two of {480 kHz, 960 kHz} for a same UE, especially under certain scenarios involving switching, such as BWP switching, beam switching and antenna switching. However, [6, Nokia] argued that keeping the absolute processing time the same for all SCSs would either considerably increase the amount of HARQ processes needed or reduce the data rate due to HARQ process starvation. On the same topic, [21, Ericsson] also examined the latency of new SCSs if keep the same absolute time as 120 kHz SCS processing and observed that UE PDSCH/PUSCH processing timelines for SCS > 120 kHz need to be further tightened compared to those for 120 kHz SCS to enable high performance NR operation in 52.6 to 71 GHz.

Moderator’s comment:

The following proposal is formulated for discussion based on the above.

##### Proposal 2-2 for discussion:

* RAN1 strives to reduce the absolute time durations of UE processing timelines for 480 kHz and 960 kHz SCS compared to those for 120 kHz SCS for NR operation in 52.6 to 71 GHz.
* Consider using exponential models for selected timelines as baseline for the discussions
  + At least for N1, N2, N3
  + FFS for other timelines
  + FFS model parameters for each selected timeline

Companies are encouraged to provide comments if any.

|  |  |
| --- | --- |
| Company Name | Comments/Views |
| Futurewei | Support moderator’s proposals, with the amendment in the first bullet “if feasible” for the reduction of UE processing timelines. |
| LG Electronics | Fine with Moderator’s proposals and Futurewei’s edition. |
| Xiaomi | Support moderator’s proposal. |

#### Dependence and order of discussion

Several contributions mentioned the dependence of determining some UE processing timeline with some related discussions.

[8, CATT] thought the UE processing time N1/N2, the ranges of k0, k1 and k2 values with 480KHz/960KHz SCS could not be determined before the maximum system bandwidth supported is finalized.

[3, ZTE] and [17, LG] proposed to consider the phase noise estimation and compensation time on timeline design.

[19, Xiaomi] and [20, Samsung] proposed that impacts on PDSCH/PUSCH processing time (N1/N2) and/or PDCCH processing timeline may need to consider maximum number of BDs/CCEs for multi-slot span PDCCH monitoring.

[21, Ericsson] proposed that RAN1 should strive to narrow down the range of UE processing latencies early in the WI phase, particularly those related PDSCH/PUSCH processing (N1, N2, N3), to enable multi-PDSCH/PUSCH design to proceed.

[24, Apple] suggested an order for discussion with three groups, (1) independently specified, (2) dependent on the values of group 1, (3) dependent on progress in other sub-agenda items.

Moderator’s comment:

It is true that some UE processing timelines may depend on progress of discussions in other sub-agenda items. On the other hand, the decision on possible range of some UE processing timelines may facilitate the discussion for other timeline determination as well as for other enhancements in this WI.

##### Proposal 2-3 for discussion:

* The following UE processing timelines are prioritized for discussion
  + PDSCH processing time (N1), PUSCH preparation time (N2), HARQ-ACK multiplexing timeline (N3)
  + CSI processing time, Z1, Z2, and Z3, and CSI processing units

Companies are encouraged to provide comments and/or suggestions if any.

|  |  |
| --- | --- |
| Company Name | Comments/Views |
| Futurewei | In principle we agree with moderator’s proposal. However, it needs to be clarified if these are prioritized over other timelines discussions. In addition, some of the timelines may be dependent on the multi-PDSCH/PUSCH scheduling discussion. |
| LG Electronics | Support Moderator’s proposal. |
| Xiaomi | Support moderator’s proposal. |

#### Additional processing timelines

[24, Apple] proposed to investigate the need for enhancements and standardization, of the following processing timelines:

• Default PUSCH time Domain resource allocation for normal CP

• UE PDSCH reception preparation time with cross carrier scheduling with different subcarrier spacings for PDCCH and PDSCH

• SRS, PUCCH, PUSCH, PRACH cancellation with dynamic SFI

• ZP CSI Resource set activation/deactivation

• Beam Switch Timing for periodic CSI-RS + aperiodic CSI-RS

• Beam switch timing for aperiodic CSI-RS

• Aperiodic CSI-RS timing offset

• Application delay of the minimum scheduling offset restriction

• SRS triggering after DCI reception

Moderator’s comment:

The above proposal seems just encouraging to investigate the need of enhancements for the listed sub-bullets. In this case, it seems no need to have an agreement.

Companies are encouraged to provide comments if any.

|  |  |
| --- | --- |
| Company Name | Comments/Views |
| Futurewei | We think that we should strive to keep the same timeline for beam switching, see our reply for 2.2.2.5 |
| Xiaomi | For the first bullet, what’s the motivation of defining default PUSCH time Domain resource allocation? |
|  |  |

#### Proposals on some specific timelines

[1, Futurewei] proposed the new values for the beamSwitchTiming corresponding to SCS {480kHz and 960 kHz} use ENUMERATED {sym14, sym28, sym48, sym224, sym336} as starting point.

[3, ZTE] proposed to discuss how to interpret k0, k1 and k2 for PUSCH/PDSCH scheduling and HARQ feedback timing indication.

[5, Huawei] proposed the definitions of k0 and k1 for multi-PDSCH/PUSCH scheduling.

[6, Nokia] argued that in Rel-15, N\_CPU is independent from numerology, and proposed that the existing specification can be reused for 480kHz and 960kHz SCS

[19, Xiaomi] proposed to specify different default K1 value sets for different SCS, and each K1 set with a maximum number of 8 values to keep the K1 bit field in DCI 1-0/1-1/1-2 unchanged.

[20, Samsung] proposed to support SCS-specific K1/K2 by reusing existing default/configured K1/K2 plus a SCS specific offset.

[21, Ericsson] proposed to increase the range of K0/K1/K2 for multi-PDSCH/PUSCH scheduling.

[25, Qualcomm] proposed that for HARQ timing indication K1, uses the last PDSCH granted in the multi-PDSCH grant as reference slot.

[26, NTT DoCoMo] proposed that for K0/K1/K2 set, consider proper K0/K1/K2 set configuration and define default values for new SCSs.

Moderator’s comment:

For those proposals on some specific timelines, suggest to discuss more.

Companies are encouraged to provide comments and/or suggestions on agreeable proposals if any.

|  |  |
| --- | --- |
| Company Name | Comments/Views |
| Futurewei | We think that we should strive to keep the same timeline for beam switching ENUMERATED {sym14, sym28, sym48, sym224, sym336} even for larger SCS. Discuss if for larger values {sym224, sym336} are other factors such as RF/antenna limit that need to be considered. It may require keeping the absolute time values constant while adapting the symbol numbers. |
| LG Electronics | In our view, some issues can be discussed in other sub-agenda, e.g., AI 8.2.4. |
|  |  |

#### Other issue(s)

Please provide comments if any on any missed issue(s) about timeline.

|  |  |
| --- | --- |
| Company Name | Comments/Views |
|  |  |
|  |  |
|  |  |

## 2.3. PTRS

### Individual observations/proposals

The following are individual observations/proposals from the contributions.

|  |  |
| --- | --- |
| Sources | Observations/proposals |
| [1, Futurewei] | Observation 4: With ICI cancellation for SCS 120kHz, 480kHz, and 960kHz, block-PTRS does not offer BLER performance gain over comb-PTRS across the entire SNR range. Reducing PTRS density from K=2 to K=4 leads to a BLER performance loss up to 1dB.  Proposal 6: With higher SCSs employed, a comprehensive evaluation of the effect of frequency-selectivity on the accuracy of channel estimation, and on the link performance is necessary.  Proposal 7: With ICI cancellation for SCS 120kHz, 480kHz, and 960kHz, the comb-PTRS with sufficient frequency-domain is recommended. Study the block-DMRS enhancement and other efficient DMRS structures that could lead to comparable performance with the ½ comb-DMRS.  Observation 5: The advantage of block structure of PTRS is smaller than having PTRS tones as spread as possible for ICI cancellation.  Proposal 8: Reuse the comb-PTRS structure for NR-U 52.6 to 71GHz and not to pursue either single or multi-block PTRS. |
| [3, ZTE] | Observation 2: ICI compensation based on legacy PTRS can achieve similar or better performance compared with block PTRS and hybrid PTRS under the same PTRS overhead.  Observation 3: The calculation complexity of ICI compensation based on legacy PTRS, block PTRS and hybrid PTRS is similar.  Proposal 4: Reuse the Rel-15 legacy PTRS pattern for 52.6GHz~71GHz. |
| [5, Huawei] | Proposal 1: Reuse the physical design and framework defined in FR2 for 120 kHz, except PTRS.  • From RAN1 specification perspective, 120 kHz SCS can be supported in 52.6-71 GHz with no specification change by simply extending FR2 up to 71 GHz.  Observation 3: Both theoretical analysis and simulation results show that ICI compensation for 960 kHz with high MCS is necessary. Based on the theoretical analysis of the relationship between equivalent ICI and SCS, the same observation applies to the SCS smaller than 960 kHz, like 120 kHz and 480 kHz.  Observation 4: Block PTRS sequence with constant modulus in time domain provides better performance than distributed PTRS.  Observation 5: Block PTRS has more versatility in different scenarios than distributed PTRS, including power boosting and UE with narrow scheduled bandwidth.  Proposal 10: Support block PTRS with ZC sequence for 120 kHz, 480 kHz and 960 kHz SCS with CP-OFDM.  Observation 6: With the PTRS pattern defined in Rel-15 for DFT-s-OFDM, BLER performance of 64QAM with 120 kHz SCS reaches a floor above 10-2 due to the longest interpolation range, and it can be improved by using a new pattern with more PTRS groups.  Proposal 11: A new PTRS pattern with more PTRS groups within one DFT-s-OFDM symbol should be considered to allow scheduling over large bandwidth.  Observation 7: Due to Rx timing shift, (at least part of) a PTRS group placed at the tail of the transmitter’s DFT-s-OFDM symbol, may wrap-around to the head of the symbol from the receiver’s perspective, thus spoiling the original intention of the design and unnecessarily increasing Rx complexity, as well as deteriorating PN compensation performance.  Proposal 12: For PTRS with , the mapping of last PTRS group should consider potential Rx timing shift and avoid the last X pre-DFT symbol(s). |
| [6, Nokia] | Observation 12. Existing PTRS configurations provide good allocation flexibility to achieve good performance for any bandwidth, SCS, or MCS.  Observation 13. Existing PTRS configurations provide the best performance for CPE compensation, and increasing frequency density does not provide any gain.  Observation 14. CPE compensation cannot provide reasonable performance for 120kHz SCS with 400MHz bandwidth when 64-QAM is used.  Observation 15. CPE compensation cannot provide reasonable performance for 480kHz SCS with 1600MHz bandwidth when 64-QAM is used.  Observation 16. CPE compensation provides good performance for 960kHz SCS with 2000MHz bandwidth even when 64-QAM is used.  Observation 17. Existing PTRS configurations provide the best performance for ICI compensation, and increasing frequency density does not provide any gain.  Observation 18. Phase noise compensation is an implementation specific aspect.  Proposal 8. Use existing PTRS configurations for CP-OFDM.  Observation 19. PUSCH performance of DFT-s-OFDM may be improved by increasing the maximum number of PTRS groups with well affordable PTRS overhead.  Observation 20. New PTRS configurations can give many dBs performance gains for high order modulations.  Proposal 9. Consider increasing number of PTRS groups for DFT-s-OFDM to make high order modulations robust to phase noise when a large number of PRBs is used. |
| [9, vivo] | Proposal 2: Reuse Rel-15 PTRS structure based on OFDM for NR operation from 52.6GHz to 71GHz. |
| [10, Mitsubishi] | Observation 1: In bands above 52.6GHz, the ICI component of the phase noise becomes predominant on CPE.  Observation 2: Distributed PT-RS pattern shows poor performance results with CPE phase noise estimation regardless of the PT-RS pattern density.  Observation 3: For a distributed PT-RS pattern, de-ICI Wiener filtering outperforms CPE in all cases, but high MCS still not reach FER=0.1.  Observation 4: Distributed PT-RS patterns are not robust enough to ensure system performance in bands above 52.6GHz.  Observation 5: For a similar overhead, block PT-RS (with any ordinary sequence) is outperformed by distributed PT-RS pattern when a same de-ICI Wiener filter is used at the receiver side.  Observation 6: Block PT-RS with cyclic sequence significantly outperforms the distributed PT-RS pattern with ICI compensation.  Observation 7: Block PT-RS with cyclic sequence requires lower complexity phase noise compensation filtering than the de-ICI filter needed for the distributed PT-RS pattern.  Proposal 1: Support block PT-RS with cyclic sequence for OFDM waveform.  Proposal 2: A PT-RS sequence for OFDM waveform composed of KP samples includes a cyclic prefix of floor(KP/2) samples.  Proposal 3: Support density extension of current Rel.15 PT-RS for DFTsOFDM waveform. |
| [11, MediaTek] | Observation 1: When ICI equalizer is used at the receiver, R-15 PTRS & DMRS design could support normal NR operation with 120 KHz SCS and high MCS at 60 GHz band.  Proposal 1: No DMRS and PTRS enhancements are needed for NR operating at 60 GHz band with 120 KHz SCS. |
| [15, InterDigital] | Observation 8: Enhanced PT-RS does not show significant performance benefits for 480 kHz and 960 kHz.  Proposal 6: PT-RS enhancement for 480 kHz and 960 kHz is not considered for NR 52.6 – 71 GHz. |
| [17, LG] | Observation #1: ICI compensation is required at least for 120 kHz SCS to reduce the performance degradation at high MCS.  Observation #2: The performance gap between the absence of phase noise (PN) and the PN compensation is still observed (about 1 dB at 10% PDSCH BLER) for all SCSs, where phase noise compensation is performed with the least-square (de-ICI filtering) or CPE only compensation.  Proposal #8: PT-RS enhancements can be further considered for all SCSs and high MCS (e.g., 64QAM). |
| [20, Samsung] | Proposal 12: Consider increasing the frequency domain PT-RS density for smaller RB allocation.  - For Rel-15 PT-RS design, consider K=1 as a valid configuration.  - Chunk based PT-RS design offers more flexibility for increasing the frequency domain density of PT-RS.  Proposal 13: For higher data rate (MCS28) with 120kHz SCS, investigate chunk based PT-RS patterns approach when UE complexity is a concern. |
| [21, Ericsson] | Observation 3 Enhanced PT-RS structure with 1 PT-RS symbol every RB (K = 1) does not provide additional performance gain over the existing Rel-15 PT-RS structure (K = 2).  Observation 4 Clustered PT-RS structure can frequently collide with existing NR reference symbols (such as CSI-RS and TRS) with no simple avoidance solution.  Observation 5 A clustered PT-RS structure does not offer a performance advantage over the existing Rel-15 NR distributed PT-RS structure.  Proposal 13 Retain the same Rel-15 distributed PT-RS design for OFDM for NR operation in 52.6 to 71 GHz. Increasing the frequency domain density of PTRS compared to Rel-15 does not provide gains. |
| [22, CEWiT] | Proposal 1: Support for new PT-RS design for NR above 52.6GHz at least for 120KHz SCS.  Proposal 2: Support Block-PTRS as one of the candidates for new PTRS design for NR above 52.6GHz.  Observation 1: The specification impact due to the introduction of new PTRS design should be carefully studied.  Proposal 3: Time density based on MCS, as in FR1 and FR2, is supported. |
| [24, Apple] | Proposal 12: RAN1 should support frequency domain power boosting for PTRS where regulations allow and new PTRS patterns to mitigate time varying phase noise with each symbol. |
| [25, Qualcomm] | Observation 1: With a block PTRS pattern and ICI compensation algorithm,  • The performance of block PTRS improves as the number of clusters increases, due to the higher frequency diversity.  • For the same block PTRS pattern, Algorithm 1 (direct de-ICI filtering) outperforms Algorithm 2 (ICI filter approximation).  • For the same ICI compensation algorithm, the legacy PTRS pattern outperforms the block PTRS pattern.  Proposal 1: As PTRS enhancement for assisting ICI compensation, increasing the frequency domain PTRS density for small RB allocation can be considered. New PTRS patterns other than the Rel-15 design, such as the block PTRS patterns, are not necessary.  Observation 2: For ICI compensation (direct de-ICI filtering) with the legacy PTRS pattern,  • The performance improves with the increasing number of de-ICI filter taps (3 to 5 taps).  • With a fixed transport block size, the performance improves as the PTRS overhead decreases.  o The performance loss due to increased effective code rate is more pronounced at higher MCSs.  • With a fixed effective code rate, the performance slightly improves as the PTRS overhead increases.  Observation 3: When ICI compensation is applied to 120kHz SCS,  • At MCSs 22 and 24, 120kHz SCS with ICI compensation performs almost equal to 960kHz SCS with CPE-only compensation.  • At MCS 26, 120kHz SCS with ICI compensation suffers from residual ICI and is outperformed by 960kHz SCS with CPE-only compensation.  Proposal 2: For SCS 120kHz, supporting the MCSs that require ICI compensation should be based on the UE capabilities. |

### Summary on PTRS

#### For CP-OFDM

As required by the WID regarding whether there’s a need for PTRS enhancement, the following sources evaluated and compared CPE and/or ICI PN compensation performance using the existing Rel-15 NR distributed PTRS structure against new PTRS patterns.

[1, Futurewei] evaluated PDSCH with CP-OFDM performance for all SCSs between comb- and block-PTRS with optimal number of de-ICI filter taps for each SCS. It is observed block-PTRS does not offer BLER performance gain over comb-PTRS across the entire SNR range. (Moderator’s note, it showed ~0.5 dB loss for block-PTRS). It further evaluated multi-block-PTRS, i.e., the PTRS tones in each symbol are separated into a designated number of blocks and observed again no gain for block-PTRS.

[3, ZTE] evaluated PDSCH with CP-OFDM performance with the legacy PTRS, block PTRS and hybrid PTRS for 120 and 480 kHz SCS for 64QAM. It is observed that ICI compensation based on legacy PTRS can achieve similar or better performance compared with block PTRS and hybrid PTRS under the same PTRS overhead.

[5, Huawei] compared BLER performance of 120 kHz SCS with Rel-15 PTRS and block PTRS in CDL- D 20ns delay spread for MCS 22. It is observed a small performance loss (~0.2 dB) for block PTSR compared to Rel-15 PTRS. It reported a slight BLER performance gain (~ 0.3 dB) of block PTRS for 10% BLER target when a sequence with constant modulus in time domain is used with block PTRS. It further observed that with power boosting, the block PTRS performs a little better (~ 0.3 dB) than distributed PTRS, even with the sequence defined in Rel-15.

[6, Nokia] evaluated both CPE and ICI performance and observed that existing PTRS configurations provide the best performance for CPE and ICI compensation, and increasing frequency density does not provide any gain. It is also observed that phase noise compensation in general (including ICI filtering) is an implementation issue.

[9, vivo] evaluated CP-OFDM performance for CPE with Rel-15 PTRS, direct de-ICI filter with Rel-15 PTRS and ICI filter approximation with a clustered PTRS for all SCSs. It is observed that CPE or de-ICI filter with Rel-15 PTRS perform better than ICI filter approximation with a clustered PTRS.

[10, Mitsubishi] compared phase noise compensation performance for the following four cases: CPE-based with Rel-15 PTRS, de-ICI with Rel-15 PTRS, de-ICI with block PTRS and ICI filtering with block PTRS with cyclic sequence for 120 kHz SCS. It is observed that for a similar overhead, block PTRS is outperformed by Rel-15 distributed PTRS patterns when a same de-ICI Wiener filter is used at the receiver side. It also observed that the PN compensation with block-based PTRS and cyclic sequence outperforms de-ICI Wiener filtering with Rel-15 distributed PTRS.

[11, MediaTek] evaluated ICI performance with Rel-15 PTRS and reported that with a ICI equalizer at the receiver side, it is able to provide performance very close to the case when there is no phase noise.

[15, InterDigital] evaluated PN compensation performance for different PTRS density of Rel-15 PTRS and observed that the increased PTRS density does not show significant performance benefits with 480 kHz and 960 kHz SCS.

[17, LG] evaluated CPE and ICI performance with Rel-15 PTRS. It observed performance improvement of ICI compared to CPE at least for 120 kHz SCS and a performance gap (about 1 dB at 10% PDSCH BLER) between the absence of phase noise (PN) and the PN compensation for all SCSs.

[21, Ericsson] first compared CPE and de-ICI filtering performance for all SCSs with Rel-15 PTRS and increased PTRS density. It observed that increased PTRS density does not provide additional performance gain over Rel-15 PTRS. It also compared de-ICI and ICI filter approximation performance based on Rel-15 PTRS and single and multiple clusters of PTRS. It is observed that clustered PT-RS structure does not offer a performance advantage over the existing Rel-15 NR distributed PT-RS structure.

[25, Qualcomm] compared CPE and ICI performance for different PTRS. It is observed that for the same ICI compensation algorithm, the legacy Rel-15 PTRS pattern outperforms the block PTRS pattern.

In addition to BLER performance, some other aspects of PTRS are also discussed.

[5, Huawei] argued that block PTRS is better suited than Rel-15 PTRS when power boosting is applied and/or UE with narrow scheduled bandwidth. [24, Apple] also proposed to support frequency domain power boosting for PTRS where regulations allow.

Both ([10, Mitsubishi], [20, Samsung]) proposed to consider block/chunk based PTRS for ICI filter approximation due to better UE complexity than direct de-ICI filter. However, on the same topic, [3, ZTE] showed a comparable computation complexity for different ICI algorithms and [9, vivo] showed that ICI filter approximation has less complex multiplication and less complex addition but much more matrix inverse operation than de-ICI filter.

It is observed in [21, Ericsson] that clustered PTRS structure can frequently collide with existing NR reference symbols (such as CSI-RS and TRS) with no simple avoidance solution.

[20, Samsung] and [25, Qualcomm] argued that ICI compensation algorithms require larger PT-RS REs than CPE only compensation algorithm. Therefore, they proposed to consider higher frequency domain PTRS density when the allocated RBs is small.

Companies’ views regarding whether to support new block/chunk/cluster PTRS pattern for CP-OFDM are summarized below.

Yes: [5, Huawei], [10, Mitsubishi], [17, LG], [20, Samsung], ([22, CEWiT] at least for 120 kHz), [24, Apple]

No: [1, Futurewei], [3, ZTE], [6, Nokia], [9, vivo], [11, MediaTek], [15, InterDigital], [21, Ericsson], [25, Qualcomm]

Moderator’s comment:

Looking at these extensive evaluation results from all contributions, companies have different views regarding whether there is significant performance gain of new PTRS patterns compared to existing PTRS. Hence, there’s no consensus with respect to the need of PTRS enhancement.

##### Proposal 3-1 for discussion:

* Use existing PTRS design for CP-OFDM for NR operation in 52.6 to 71 GHz.

Companies are encouraged to provide comments if any.

|  |  |
| --- | --- |
| Company Name | Comments/Views |
| Futurewei | Support moderator’s proposal. |
| Mitsubishi | We do not agree with Moderator’s view. As briefly discussed online today, we saw in our evaluations that clustered PT-RS with cyclic sequence significantly outperforms Rel.15 pattern + de-ICI filter, while clustered PT-RS (single or multi-block) with non-cyclic sequence doesn’t. Most of the contributing companies have only simulated the latter case, and the lack of improvement they rightfully see comes from the non-cyclic sequence, and not from the clustered pattern. We do not agree on concluding to keep Rel.17 pattern based on these partial results. We propose to further investigate clustered/multi-block PTRS with cyclic sequence, shown to bring gain by several companies. |
| Xiaomi | Support moderator’s proposal. |

#### For DFT-s-OFDM

As required by the WID regarding whether there’s a need for PTRS enhancement, the following two sources evaluated PTRS enhancement for DFT-s-OFDM.

[5, Huawei] evaluated a new PTRS pattern with more PTRS groups within on DFT-s-OFDM symbol. It is observed that for the same overhead, BLER performance of 64QAM with 120 kHz SCS can be improved by using a new pattern with more PTRS groups within one DFT-s-OFDM symbol.

[6, Nokia] compared PUSCH performance of DFT-s-OFDM with different PTRS configurations and showed performance improvement of 64QAM with 120 kHz SCS by increasing the maximum number of PTRS groups and keeping the same number of samples per group (i.e. with increased total PTRS overhead).

Although there’s no evaluation results for DFT-s-OFDM, [10, Mitsubishi] also proposed density extension of current Rel.15 PTRS for DFT-s-OFDM waveform.

[5, Huawei] brought up another issue of PTRS group placement for PTRS with It observed that due to Rx timing shift, (part of) a PTRS group placed at the tail of the transmitter’s DFT-s-OFDM symbol, may wrap-around to the head of the symbol from the receiver’s perspective, thus deteriorating PN compensation performance.

Moderator’s comment:

Compared to CP-OFDM, there’re much less evaluation results on the performance of PTRS enhancements for DFT-s-OFDM. Two contributions showed performance gain only for a limited case (64QAM with 120 kHz SCS) which is hard to tell whether the enhancement should be applied to DFT-s-OFDM in general to all SCSs under all conditions. Companies are encouraged to evaluate other cases and clarify their proposal(s) in order to reach agreement on PTRS enhancements for DFT-s-OFDM.

##### Proposal 3-2 for discussion:

* FFS: PTRS pattern with more PTRS groups within one DFT-s-OFDM symbol when a large number of PRBs is scheduled for NR operation in 52.6 to 71 GHz.

Companies are encouraged to provide comments if any.

|  |  |
| --- | --- |
| Company Name | Comments/Views |
| Mitsubishi | Agree with Moderator’s proposal. |
|  |  |
|  |  |

#### Other issue(s)

Please provide comments if any on any missed issue(s) about PTRS.

|  |  |
| --- | --- |
| Company Name | Comments/Views |
|  |  |
|  |  |
|  |  |

## 2.4. DMRS

### Individual observations/proposals

The following are individual observations/proposals from the contributions.

|  |  |
| --- | --- |
| Sources | Observations/proposals |
| [1, Futurewei] | Observation 1: With larger SCSs and higher channel frequency-selectivity, the number of DMRS symbols within the coherence bandwidth of the channel is significantly decreased; thus, channel estimation with comb-DMRS and interpolation may be subject to excessive error.  Observation 2: Under larger DS values, the BLER performance for SCSs 480kHz and 960kHz degrades from the performance of the Rel-15 compliant comb-DMRS structure with FD interpolation. The proposed non-interpolation method with no FD averaging almost always leads to the best performance among the four CE methods. For lower SCS 120kHz, the comb-DMRS offers desirable performance.  Proposal 3: With higher SCSs employed, a comprehensive evaluation of the effect of high frequency-selectivity on the accuracy of channel estimation, and in turn, the link performance is necessary.  Proposal 4: Study if block-DMRS can be further enhanced or if there are other DMRS structures that lead to comparable performance with the ½ comb-DMRS.  Proposal 5: The necessity of recommending a dedicated DMRS format for different MCS values is not supported by the current evaluation.  Observation 3: Performance losses are observed when the type-2 DMRS over type-1 DMRS are used, especially for the higher SCS. |
| [2, Lenovo] | Observation 3: For higher SCS values such as 480kHz and 960kHz, 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.  Proposal 3: For supporting NR between 52.6 GHz and 71 GHz with high subcarrier spacing values including 480kHz and 960kHz, new DM-RS configurations should be supported with following criterion:   * High frequency density of the DM-RS for high SCS for better channel estimation when channel coherence bandwidth is less than the configured SCS * Reduced number of DM-RS ports as the performance gain of high rank MIMO channels is expected to be limited in this FR |
| [3, ZTE] | Observation 4: Rel-15 DMRS Type 1 pattern and the new DMRS pattern that fully occupied in frequency domain show comparable performance.  Proposal 5: Reuse the Rel-15 legacy DMRS pattern for 52.6GHz~71GHz.  Proposal 6: Consider to relax the restriction on DMRS ports for PUSCH and PDSCH when PTRS is configured.  Proposal 7: Consider the impact of phase noise on port number of other reference signals and control signals. |
| [4, OPPO] | Proposal 4: Enhancements to DMRS pattern for 480kHz and 960kHz SCSs in the new frequency range should be supported. |
| [5, Huawei] | Observation 2: To provide enough accuracy of channel estimation, DMRS of multiple slots should be combined for channel estimation for multi-PDSCH scheduling, which increases the delay of channel estimation if only one FL-DMRS symbol is used per scheduled slot.  Proposal 9: Support multiple consecutive symbols of FL-DMRS for the multi-slot scheduling, whose absolute time duration is same as that of 120 kHz. |
| [6, Nokia] | Proposal 5: Study the solution to support time-domain PRB bundling when multi-PDSCH scheduling is supported. The existing DMRS time-domain pattern is reused unless any critical performance degradation is identified.  Observation 21: Existing RAN1 specification provides support for flexible configuration of different DMRS antenna ports belonging into same or different CDM groups for rank-1 and rank-2.  Observation 22: For rank-1, type-1 and new type (“comb-1”) w/o OCC-2 can achieve better BLER performance of PDSCH compared with the type-2 DMRS w/o OCC-2 with SCSs =480 and 960 kHz.  Observation 23: For rank-2, both type-1 and type-2 DMRS w/o OCC-2 outperfom other DMRS types in BLER performance with SCSs=480 and 960 kHz.  Observation 24: Type-1 w/o OCC-2 outperforms in BLER performance other DMRS types in the most of the considered cases.  Observation 25: It is reasonable to provide a specification support for DMRS of PDSCH/PUSCH to be optimized only up to rank-2 in Rel-17 for at higher carrier frequencies (>52.6 GHz).  Observation 26: New DMRS type (irrespective of rank 1 or rank 2) does not provide any possibility for multiplexing of it with any other type of signal/RS/channel into same OFDM symbol.  Observation 27: Due to additional RS overhead associated with the new DMRS type, the usage of new DMRS type leads to reduced achievable PUSCH/PDSCH throughput in comparison with type-1 DMRS w/o OCC.  Observation 29: It is not feasible to introduce new DMRS type for PUSCH/PDSCH in Rel-17 for above 52.6 GHz.  Proposal 10: No additional DMRS pattern is supported in Rel-17 for above 52.6 GHz. |
| [9, vivo] | Proposal 3: Retain DMRS OCC in frequency domain based on OFDM for NR 52.6GHz to 71GHz. |
| [11, MediaTek] | Observation 1: When ICI equalizer is used at the receiver, R-15 PTRS & DMRS design could support normal NR operation with 120 KHz SCS and high MCS at 60 GHz band.  Proposal 1: No DMRS and PTRS enhancements are needed for NR operating at 60 GHz band with 120 KHz SCS. |
| [12, Intel] | Proposal 5: Indicate to UE that CDM groups, signaled in scheduling DCI, do not contain potential co-scheduled DMRS. |
| [15, InterDigital] | Observation 6: Type-2 DM-RS shows performance loss due to insufficient RS density in frequency domain.  Observation 7: Type-1 DM-RS shows performance loss due to FD-CDM in nonconsecutive REs.  Proposal 5: Support proposed DM-RS pattern for PDSCH and PUSCH with larger SCSs. |
| [16, Sony] | Proposal 9: DMRS mapping in the frequency domain should be redesigned for new SCS   At least 2 DMRS configurations for large and small delay spread environments should be specified.   For large delay spread environment, high frequency dense DMRS mapping should be considered. |
| [21, Ericsson] | Proposal 14 Support a configuration of DMRS Type-1 that disables frequency domain CDM (FD-CDM) within the same comb (CDM group) for 480/960 kHz. This results in the following restrictions:  • For single-symbol DMRS: Rank 3,4 not supported  • For double-symbol DMRS: Ranks 5 – 8 not supported |
| [22, CEWiT] | Proposal 4: Support for a new DMRS design for NR above 52.6GHz to improve channel estimation accuracy. |
| [23, Charter] | Proposal 3: High-density PDSCH DMRS (12 REs per PRB), should be considered for further enhancing performance of NR beyond 52.6 GHz. |
| [24, Apple] | Proposal 11: To account for transmission with large SCSs in low coherence BW channels,  • turn on or off the FD-OCC based on the scenario the channel is in  • configure the UE with a DMRS pattern based on the new SCSs and the coherence bandwidth of the channel |
| [25, Qualcomm] | Observation 4: For channels with larger DS, the main reason of performance degradation with the larger SCS is the loss of orthogonality, and the gain from increasing the frequency density of the DMRS tones is limited, i.e., the performances of Config.1 with no CDMing and the new configuration with no CDMing are very close to each other.  Proposal 3: For DMRS enhancement for high SCSs, while communicating over channel with large DS, for rank 1, a single port should be used from one CDM group and the remaining ports from the same group should not be assigned to other UEs. This information should be signaled to the UE via the scheduling DCI.  Proposal 4: Study DMRS bundling for multi-PDSCH/PUSCH transmission, at least for the case when there is no gap between transmissions.  Proposal 5: Study DMRS overhead reduction for multi-PDSCH/PUSCH transmission, at least for the case when there is no gap between transmissions. |
| [26, NTT DoCoMo] | Proposal 3: Denser DMRS pattern in frequency domain should be supported for new SCSs. |

### Summary on DMRS

Three aspects of DMRS enhancements are discussed in the contributions.

#### Frequency domain density and number of DMRS port

As required by the WID regarding whether there’s a need for DMRS enhancement for 480 and 960 kHz SCS, the following sources evaluated and compared BLER performance using the existing comb DMRS pattern against some new DMRS patterns.

[1, Futurewei] compared the PDSCH BLER performance based on existing comb-DMRS with different channel estimation methods against a block-DMRS of the same overhead. It is observed that non-interpolation method with no FD averaging as channel estimation based on comb-DMRS performs better than block DMRS for 480 and 960 kHz SCS under MCS7/16/22. It also compared performance of existing type-1 and type-2 DMRS and observed performance loss for type-2 DMRS for high SCS.

[2, Lenovo] also evaluated BLER performance of DMRS mapped to each RE in frequency domain and showed about 1 dB gain for 960 kHz SCS compared to existing type-1 DMRS. It also proposed to reduce number of DM-RS ports as the performance gain of high rank MIMO channels is expected to be limited in this FR.

It is observed in [3, ZTE] that for 480kHz and 960kHz, new DMRS pattern with higher DMRS density is slightly better (less than 0.5dB gain) than Rel-15 DMRS Type 1, both in low delay spread and high delay spread when ideal PN estimation and compensation is assumed.

[4, OPPO] compared performance among Type-1 DMRS pattern, Type-2 DMRS pattern and a new DMRS pattern for all SCSs under MCS16. It observed similar performance between the new FDM pattern and Type-1 FDM pattern. It also observed performance gain (0.8 dB for 480 kHz and about 1.5 dB for 960 kHz SCS) of the new CDM pattern compared to existing CDM patterns.

[6, Nokia] compared BLER performance of rank-1 and rank-2 PDSCH for different DMRS configuration options w/ and w/o OCC-2 (i.e. Rel-15 type-1, Rel-15 type-2 and new type (“comb-1”) ) without any phase noise impairments for 480 and 960 kHz SCS. It is observed that new type DMRS does not outperform Type-1 w/o OCC-2.

[15, InterDigital] compared BLER and throughput performances of Rank 2 with MCS 7 and 16 for 480 and 960 kHz SCS. It observed performance gain of an enhanced DMRS pattern with increased density.

[21, Ericsson] compared BLER performance of rank-1 PDSCH for type-1 DMRS with that of an ideal channel estimation for 480 and 960 kHz SCS. It is observed that for MCS 22/24/26/28 the gap in performance between genie/practical channel estimators is insignificant (< 0.9 dB) for all DS evaluated. In other words, there is little room for improvement using an enhanced DMRS design.

[23, Charter] compared PDSCH performance of higher-density DMRS (12 REs per PRB) with that of Rel-15 DMRS for 960 kHz SCS. It observed 0.2~0.3 dB gain for MCS22 and 1.3 dB gain for MCS26.

[25, Qualcomm] compared PDSCH performance of a new DMRS pattern featured by high frequency density (i.e., every RE) and 2-FD-OCC across adjacent REs with existing type-1 and type-2 DMRS patterns with 960kHz SCS for TDL-A channels with DS 20ns. It is observed that the gain from increasing the frequency density of the DMRS tones is limited (e.g., < 0.2 dB when CDM is off for MCS22/24/26).

[26, NTT DoCoMo] have evaluated PDSCH BLERs with 480 and 960 kHz SCS for three DMRS types with two-layer transmission, (a) Rel-15 DMRS type 1, (b) type 2, and (c) a new DMRS type with DMRS on every RE in the symbol containing DMRS. It observed about 0.5 to 1 dB gain of full-density DMRS compared to Type 1 for 480 and 960 kHz SCS in TDL-A with 10ns DS.

In addition to BLER performance, other aspects of block DMRS including the possibility for multiplexing of it with any other type of signal/RS/channel into same OFDM symbol, extra overhead and computational complexity of channel estimation are discussed in [6, Nokia].

In summary, multiple contributions ([2, Lenovo], [4, OPPO], [15, InterDigital], [23, Charter], [26, NTT DOCOMO]) showed performance gain of new DMRS patterns with increased frequency domain density while other contributions ([1, Futurewei], [3, ZTE], [6, Nokia], [21, Ericsson], [25, Qualcomm]) showed that insignificant gain or performance loss of new DMRS pattern over existing DMRS pattern.

Moderator’s comment:

In light of the available evaluation results from all contributions, it seems companies have different views and there’s no consensus regarding whether there is significant performance gain and hence the need of new DMRS patterns with increased frequency domain density compared to existing DMRS.

##### Proposal 4-1 for discussion:

* Use existing DMRS patterns for NR operation in 52.6 to 71 GHz.

Companies are encouraged to provide comments if any.

|  |  |
| --- | --- |
| Company Name | Comments/Views |
| Futurewei | Support moderator’s proposal |
| Xiaomi | Support moderator’s proposal. |
|  |  |

#### Frequency domain OCC

[6, Nokia] compared BLER performance of rank-1 and rank-2 PDSCH for different DMRS configuration options w/ and w/o OCC-2 (i.e. Rel-15 type-1, Rel-15 type-2 and new type (“comb-1”) ) without any phase noise impairments. It is observed that Type-1 w/o OCC-2 outperforms other DMRS configurations.

[9, vivo] compared PDSCH BLER performance of type-1 DMRS with and without OCC for 480KHz and 960 KHz SCS with 64QAM, while the phase noise is compensated with CPE only approach. It observed no obvious gain for 480 kHz and small gain (< 0.8 dB) for 960 kHz SCS of type-1 DMRS without OCC only at large delay spread.

[12, Intel] evaluated PDSCH performance with and without frequency domain OCC being enabled for DMRS. For higher order modulation such as 64QAM (MCS 22), it observed the performance drop when OCC is enabled.

[21, Ericsson] compared BLER performance of rank-2 PDSCH for type-1 DMRS with and without FD-CDM against that of an ideal channel estimation for 480 and 960 kHz SCS. It is observed that for MCS 22/24/26/28, there’s performance gain without FD-CDM especially for large DS and very high MCS.

[24, Apple] evaluated PDSCH performance of type-1 DMRS with and without FD-OCC for 960 kHz SCS. It observed that at high frequency selectivity (low coherence bandwidth for large delay spread) there is a benefit in turning off the FD-OCC and at lower frequency selectivity (high coherence bandwidth with small delay spread), there is no difference in the performance.

[25, Qualcomm] compared PDSCH performance of a new DMRS pattern featured by high frequency density (i.e., every RE) and 2-FD-OCC across adjacent REs with existing type-1 and type-2 DMRS patterns with 960kHz SCS for TDL-A channels with DS 20ns. It is observed that for channels with larger DS, the main reason of performance degradation with the larger SCS is the loss of orthogonality. It showed performance gain without CDM for MCS22/24/26.

Based on the evaluation results, multiple sources [12, Intel], [21, Ericsson], [24, Apple], [25, Qualcomm] proposed to support a configuration of Type-1 DMRS where FD-CDM can be turned off, that is for rank 1, a single port should be used from one CDM group and the remaining ports from the same group should not be assigned to other UEs. [12, Intel] and [25, Qualcomm] further proposed to indicate this to UE via DCI.

Moderator’s comment:

Four sources ([12, Intel], [21, Ericsson], [24, Apple], [25, Qualcomm]) explicitly proposed to turn off FD-OCC, while one source ([9, vivo]) suggested to retain OCC. The following proposal is formulated based on the above for discussion.

##### Proposal 4-2 for discussion:

* Support a configuration of DMRS where OCC can be turned off within the same CDM group for 480 kHz and 960 kHz SCS in 52.6 to 71 GHz
* The indication when OCC is off is signaled to UE via DCI.

Companies are encouraged to provide comments if any.

|  |  |
| --- | --- |
| Company Name | Comments/Views |
| Futurewei | We support the first bullet. For the second one we think that should be FFS at this time. |
| LG Electronics | Same view with Futurewei. |
|  |  |

#### Multi-slot DMRS

In [5, Huawei], it proposed multiple consecutive symbols of FL-DMRS for the multi-slot scheduling. Similar considerations are mentioned in [25, Qualcomm] to study DMRS bundling and DMRS overhead reduction for multi-PDSCH/PUSCH transmission, at least for the case when there is no gap between transmissions. On the same topic, [6, Nokia] proposed to use the existing DMRS time-domain pattern for multi-slot scheduling unless any critical performance degradation is identified.

Moderator’s comment:

With limited input on this topic, suggest companies to study further and have more concrete proposals to discuss.

Companies are encouraged to provide comments and/or suggestions on agreeable proposals if any.

|  |  |
| --- | --- |
| Company Name | Comments/Views |
| Futurewei | We support further DMRS enhancements for multi-slot scheduling if they provide performance benefits. |
| LG Electronics | In our view, there’s no strong motivation to study more about it now. |
| Xiaomi | Open to discuss if it shows considerable benefits from simulation. |

#### Other issue(s)

Please provide comments if any on any missed issue(s) about DMRS.

|  |  |
| --- | --- |
| Company Name | Comments/Views |
|  |  |
|  |  |
|  |  |

# Conclusion

TBD

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