**3GPP TSG RAN WG1 Meeting #103-e R1-200yyyy**

**E-meeting, October 26th – November 13th, 2020**

**Source: Moderator (vivo)**

**Title: Summary of link level evaluation results and related issues on supporting NR from 52.6 GHz to 71 GHz**

**Agenda item: 8.2.3**

**Document for: Discussion and decision**

# Introduction

In this contribution, we summarize observations and issues regarding link level evaluation results in the Study Item (SI) of supporting NR from 52.6 GHz to 71 GHz. Note that the collection of all evaluation results including both link and system level submitted to [102-e-Post-NR-52-71GHz-01] is captured in R1-2007485.

Section 2 contains the summary of observations based on the link level evaluation results in the submitted contributions from agenda 8.2.1 and 8.2.3. Section 3 contains the summary of remaining issues related to evaluation assumptions based on the submitted contributions from agenda 8.2.1 and 8.2.3.

# Observations on link level evaluation results

In this section, we provide a summary of observations and proposals on link level evaluation results discussed in the submitted contributions.

As agreed in RAN1#101-e, the primary objective of the evaluation is to evaluate performance of PDSCH/PUSCH including study of phase noise impairment impact for various numerology (i.e. subcarrier spacing, CP length) and possibly for various carrier frequencies. The evaluation KPI(s) include BLER. The secondary objective of the evaluation is to evaluate performance of SSB/PRACH including study of phase noise impairment impact for various numerology (i.e. subcarrier spacing, CP length) and possibly for various carrier frequencies. Evaluation KPI(s) include miss-detection, and false alarm.

Table 1 Link level evaluation assumptions and parameters

| Assumptions | Value |
| --- | --- |
| Carrier Frequency [GHz] | 60 GHz    Optional: 70 GHz |
| Subcarrier Spacing [kHz] | PDSCH/PUSCH:  - {120, 240, 480, 960} kHz  -optional: 1920 kHz  Optional:  - if evaluated companies are asked to provide information on other channels/signals and subcarrier spacing |
| Bandwidth [MHz] | PDSCH/PUSCH:  - {400, 2000} MHz    Optional:  - Companies are asked to provide information if other bandwidths are evaluated  Note: Evaluation of listed channel bandwidth does not mean RAN1 has agreed to support such channel bandwidth and are only for evaluation purposes to obtain useful insights. |
| Number of RB | For 400 MHz:  - 256 (120 kHz),  - 128 (240 kHz),  - 64 (480 kHz),  - 32 (960 kHz),  - N/A (1920 kHz)  For 2000 MHz:  - N/A (120 kHz),  - N/A (240 kHz),  - 320 (480 kHz) (optional),  - 160 (960 kHz),  - 80 (1920 kHz),    For other channel bandwidths:  - Companies are asked to provide information. Companies are encouraged to utilize linearly scaled PRB sizes for a given bandwidth based on above.  Note: Other bandwidth and sub-carrier spacing combinations can be optionally used. |
| Waveform | For PDSCH:  CP-OFDM  For PUSCH:  CP-OFDM and DFT-s-OFDM |
| CP Type | Normal CP  Extended CP  Note: ECP is not expected to be applicable in all SCS and channel conditions, and companies providing results for ECP are encouraged to provide evaluation results with motivation/justification of simulated ECP cases |
| Channel Model | TDL model as defined in of TR38.901 Section 7.7.2:  - TDL-A (5ns, 10ns, 20ns DS)  - optional DS for consideration: 40ns, 60ns DS  CDL model as defined in of TR38.901 Section 7.7.1:  - CDL-B (20ns, 50ns DS)  - CDL-D (20ns, 30ns DS) with K-factor = 10 dB  - optional DS for consideration: 100ns DS  Optional modification CDL-B/D model  (a) Indoor Office NLOS: CDL-B (20 ns DS), and Indoor Office LOS: CDL-D (20 ns DS)  - Use mean angular spread values from Table 7.5.6-Part2 (for ASD, ASA, and ZSA) and Table 7.5-10 (for ZSD)  - Use mean angles of CDL-B/D for desired mean angles as baseline (no angle translation)  - Note that the angular spread values in the table are quoted in log units  - Mean K-factor for CDL-D from Table 7.5.6-Part2 (9 dB)  (b) UMi – Street Canyon NLOS: CDL-B (50 ns DS), and UMi – Street Canyon LOS: CDL-D (30 ns)  - Use mean angular spread values from Table 7.5.6-Part1 (for ASD, ASA, and ZSA) and Table 7.5-8 (for ZSD).  - Use mean angles of CDL-B/D for desired mean angles as baseline (no angle translation)  - Note that the angular spread values in the table are quoted in log units  - Use mean K-factor for CDL-D from Table 7.5.6-Part1 (7 dB)  Note: Mean angular spread values are used as desired AS value to scale the ray angles as described in TR38.901 section 7.7.5.1. As baseline, the ray angles are not translated, meaning (TR38.901 section 7.7.5.1). If companies perform translation of the ray angles they are encouraged to report the details. The mean K-factor is used to scale the tap powers as described in TR38.901 section 7.7.6.  Note 2: for TDL/CDL model, the delay spread (DS) value mentioned is the delay spread scaling value (i.e. corresponding to normalized delay of 1.0).  Note 3: Other models (either TDL or CDL) with DS values not listed are optional.  Note 4: Companies are encouraged to provide evaluation results with motivation/justification of simulated DS values. |
| Antenna Configuration (Mg,Ng,M,N,P) | For TDL model:  - 2x2  - 1x2 (optional)  For CDL model:  Configuration 1:  - (Mg,Ng,M,N,P) = (1,1,8,16,2) BS with (0.5 dv, 0.5 dH)  - (Mg,Ng,M,N,P) = (1,1,4,4,2) UE with (0.5 dv, 0.5 dH)  Configuration 2:  - (Mg,Ng,M,N,P) = (1,1,4,8,2) BS with (0.5 dv, 0.5 dH)  - (Mg,Ng,M,N,P) = (1,1,2,2,2) UE with (0.5 dv, 0.5 dH) |
| Mobility | 3 km/hr |
| PA Model | Optional:  - Companies to provide modelling (in lieu of pre-loaded Tx EVM) |
| gNB TRP PN Model | 3GPP TR38.803 example 2 BS PN profile  Optional:  - If other PN profile is used, companies to provide information on the modelling used  Note: companies to provide information about the LO distribution model assumed in the simulations. |
| UE PN Model | 3GPP TR38.803 example 2 UE PN profile  Optional:  - If other PN profile is used, companies to provide information on the modelling used  Note: companies to provide information about the LO distribution model assumed in the simulations. |
| Pre-loaded Tx EVM | Optional:  - 3% at Tx (In lieu of PA model),  - If other values are used companies are asked to provide information on the values selected for simulation. |
| Additive Rx EVM | Optional:  - 5% at Rx,  - If other values are used companies are asked to provide information on the values selected for simulation. |
| I-Q Imbalance | Optional:  - (-26dBc),  - (-31dBc),  - If other values are used companies are asked to provide information on the values selected for simulation. |
| Frequency Offset | Optional:  - 0.1 ppm (for PDSCH/PUSCH)  - 5, 10, 20 ppm (for initial access) |
| Channel Estimation | Realistic channel estimation |
| Transmission Rank | Rank 1  Note: companies are asked to provide information the precoding scheme (including granularity) used in the evaluations. |
| PDSCH SLIV | (S=2, L=12)  Optional:(S=0, L=14)  Note: Starting symbol, S, (indexed from 0) and length, L. |
| DMRS Configuration | 1 DMRS symbol (front loaded), or 2 DMRS symbols at (2,11) symbol index  Note: no data multiplexing is assumed in DMRS symbols |
| PTRS Configuration | For CP-OFDM:  (K = 4, L = 1) or (K = 2, L = 1)  Note: PTRS per K number of PRBs, and PTRS every L number of OFDM symbols  For DFT-s-OFDM:  (Ng = 2, Ns = 2, L = 1)  (Ng = 2, Ns = 4, L = 1)  (Ng = 4, Ns = 2, L = 1)  (Ng = 4, Ns = 4, L = 1)  (Ng = 8, Ns = 4, L = 1)  Note: Ng number of PT-RS groups, Ns number of samples per PT-RS group, and PTRS every L number of DFT-s-OFDM symbols  Note 2: companies are asked to provide the PT-RS configuration used for DFT-s-OFDM simulation among the listed above, where the selection of the PT-RS is chosen such that it provides similar overhead as the chosen PT-RS configuration for PUSCH CP-OFDM (if simulated). |
| CSI-RS / TRS | CSI-RS/TRS is assumed to be off (for RS overhead) |
| MCS/TBS | From MCS Table 1 (TS38.214):  - MCS 7 (QPSK),  - MCS 16 (16QAM),  - MCS 22 (64QAM),  From MCS Table 2 (TS38.214):  - MCS 27 (256QAM) (optional)  Assume NohPRB = 0 for MCS calcuations.  Note: If normal CP and extended CP are to be compared, companies are asked to provide information on the MCS values used that provide similar payload sizes for the comparison. Companies to provide actual code rate used in the evaluations. |

The above table was agreed in last RAN1 meeting as the LLS evaluation assumptions.

## 2.1. PDSCH/PUSCH performance

Multiple sources submitted evaluation results on PDSCH/PUSCH BLER performance based on the above LLS evaluation assumptions and some are evaluated with optional assumptions. The observations are summarized on the impact of SCS, delay spread and CP type, DFT-s-OFDM waveform, ICI and PTRS, DMRS in the following sub-sections.

Sixteen sources ([61, Ericsson], [68, Huawei], [26, Qualcomm], [56, vivo], [60, ZTE], [64, OPPO], [10, Nokia], [2, 55, Lenovo], [21, Apple], [18, Samsung], [23, MediaTek], [1, Futurewei], [25, NTT DOCOMO], [12, Intel], [67, Charter], [7, InterDigital]) evaluated PDSCH/PUSCH BLER performance with different SCS.

### SCS impact for CP-OFDM

#### Individual observations

The following are individual observations directly extracted from these sources.

###### [[1], Futurewei]

It evaluated 120, 240, 480 and 960 KHz SCS with ICI filter to cancel the PN impact. The optimal number of taps for ICI filter is decided to be {1,3,5,7} FD filter taps for {960 kHz, 480kHz, 240 kHz, 120 kHz} SCS respectively, where 1-tap filter is equivalent to CPE compensation. The following observations are made.

Observation 3: With the ICI filter, all analyzed SCS provide similar performance for DS=10ns at the cost of additional signal processing required by the ICI filtering.

###### [[2], Lenovo]

It evaluated PDSCH with different SCS values including 120kHz, 240kHz, 480kHz, 960kHz and 1920MHz with different MCS values including MCS7 (QPSK), MCS16 (16QAM) and MCS22 (64QAM) in TDL-A channel. The following observations are made.

Observation 1: For lower MCS (QPSK) and mid-range MCS (16QAM), there is minor performance difference between different SCS values up to 960kHz with 400MHz bandwidth.

Observation 2: For higher MCS (64QAM), there is considerable performance gain, with 960kHz performing the best, while 120kHz performing the worst with 400MHz bandwidth.

Observation 3: For higher MCS (64QAM), for 10% BLER target, the performance is almost same for 960kHz and 480kHz subcarrier spacing, but for 1% BLER target, the performance for 960kHz is significantly better than 480kHz

Observation 4: For lower MCS (QPSK) and mid-range MCS (16QAM), there is minor performance difference between 960kHz and 1920kHz with 400MHz bandwidth.

Observation 5: For higher MCS (64QAM), there is some performance gain with 1920kHz in comparison to 960kHz

###### [[55], Lenovo]

It evaluated PDSCH with different SCS values including 120kHz, 240kHz, 480kHz, 960kHz and 1920MHz with different MCS values including MCS7 (QPSK), MCS16 (16QAM) and MCS22 (64QAM) in CDL channel. The following observations are made.

Observation 1: For lower delay spread, low-mid range MCS and normal cyclic prefix, there is no significant performance difference for target BLER between different subcarrier spacing values

Observation 2: For lower delay spread, higher MCS and normal cyclic prefix, 960kHz subcarrier spacing performs the best and with significant performance difference for target BLER of 1%, that might be needed for URLLC

Observation 3: For higher delay spread and normal cyclic prefix, 960kHz subcarrier spacing performs the worst and target BLER cannot be reached for high MCS

Observation 4: For higher delay spread and extended cyclic prefix, 960kHz subcarrier spacing performance is significantly improved compared to normal cyclic prefix

Observation 5: For lower delay spread, low-mid range MCS and normal cyclic prefix, there is no significant performance difference in terms of spectral efficiency between different subcarrier spacing values

Observation 6: For lower delay spread, higher MCS and normal cyclic prefix, 960kHz subcarrier spacing performs the best and reaches the peak spectral efficiency at much lower SNR

Observation 7: For higher delay spread and normal cyclic prefix, 960kHz subcarrier spacing performs the worst

Observation 8: For higher delay spread and extended cyclic prefix, 960kHz subcarrier spacing performance is significantly improved compared to normal cyclic prefix and it performs slightly better than 480kHz for high MCS

###### [[3], Huawei]

It evaluated 120, 240, 480 and 960 KHz SCS in 400MHz CDL channel with only CPE compensation for MCS 7/16/22 with CP-OFDM, and with both CPE and ICI compensation for MCS 22 of CP-OFDM. In [3], it is observed “all the examined SCSs of 120, 240, 480, and 960 kHz achieve a similar BLER for QPSK and 16-QAM modulations” and “64-QAM is more sensitive to the phase noise and larger SCSs (480 and 960 kHz) perform considerably better than smaller SCSs (120 and 240 kHz) when only CPE compensation is carried out.”. In addition, the following observation is made.

Observation 1: For CP-OFDM, using SCS of 120 kHz or 240 kHz can achieve a similar PDSCH BLER as using 480 kHz or 960 kHz for QPSK, 16QAM and 64QAM with suitable phase noise compensation method.

###### [[68], Huawei]

Observation 1: For QPSK and 16QAM, SCSs larger than 120 kHz do not achieve a significantly better BLER. For 64QAM, a larger SCS performs better than a smaller SCS without ICI compensation. Block-based PTRS enables ICI compensation for smaller SCSs and helps a smaller SCS to perform even better than a larger SCS.

Observation 2: If CDL-B DS=50ns channel model is considered, the BLER performance of a subcarrier spacing larger than 480 kHz decreases a lot due to the short CP length.

Observation 3: When both the impact of phase noise and CP length on BLER performance are considered, simulation results show that a smaller SCS (120 kHz or 240 kHz) with NCP is the best solution if block-based PTRS for ICI compensation is introduced.

###### [[5], vivo]

It evaluated 120, 240, 480 and 960 KHz SCS with TDL-A channel model with 5, 10, 20 and 40ns DS for both 400MHz and 2GHz bandwidth. The following observations are made.

Observation 1: For 400MHz carrier bandwidth, (120K, NCP) and (240K, NCP) work well for low order modulation schemes (e.g. QPSK and 16QAM) but not for high order modulation scheme (e.g. 64QAM).

Observation 3: For high order modulation scheme (e.g. 64QAM), both (480K, NCP/ECP) and (960K, NCP/ECP) work well for 400MHz carrier bandwidth but (480K, NCP/ECP) doesn’t work well for 2000MHz carrier bandwidth.

###### [[56], vivo]

Observation 2: High order modulation is more sensitive to phase noise impact. Higher SCS benefits more with phase noise compensation than lower SCS, especially for high order modulation such as 64QAM.

Observation 3: For CP-OFDM waveform, SCS 960 KHz is the most affected because of its shortest CP coverage when the DS is increased to 40 ns.

Observation 4: The greater the bandwidth, the greater the number of RBs, resulting in more ICI impact.

Observation 5: For CP-OFDM, the larger SCS is more sensitive to DS.

###### [[7], InterDigital]

*Observation 1: Larger subcarrier spacings such as 480 kHz and 960 kHz mitigate the RF impairments in higher frequency especially for higher modulation order.*

###### [[10], Nokia]

*Observation 4: For 960 kHz SCS, 64QAM provides robust performance already with a simple CPE compensation while 480 kHz SCS suffers from a major performance degradation due to phase noise.*

*Observation 6: OFDM with CPE compensation*

* *Only QPSK and 16-QAM can be supported with SCS<960 kHz.*
* *64-QAM requires SCS=960 kHz with reasonable performance.*
* *Delay spread 5 or 10ns does not have big impact on the result, except that 1920kHz SCS suffers some performance loss for 10ns, which may be due to the too small CP size.*

###### [[12], Intel]

Observation 8:

* *The support of a high-order modulation, e.g., 64QAM, for systems operating in 52.6—71 GHz frequency range under various propagation channel conditions requires a large SCS, e.g., 960 kHz.*
* *In some propagation channel conditions, especially with low selectivity, 64QAM modulation can be supported with SCS=1920 kHz and even with SCS=480 kHz.*
* *Smaller SCS values, including those ones currently supported in NR Rel-15 for FR2, result in BLER performance degradation for 64QAM under various propagation channel conditions but can be used with 16QAM modulation.*
* *The values of SCS larger than 1920 kHz result in the short CP length which is insufficient to cope with ISI under propagation channels with relatively high frequency selectivity.*

###### [[13, 60], ZTE]

Observation 4: Phase noise has limited impact on QPSK and 16QAM modulation, and with PTRS CPE compensation, different SCS (120 kHz, 240 kHz, 480 kHz, 960 kHz) shows similar performance.

Observation 5: Phase noise has significant impact on 64QAM modulation, and with PTRS CPE compensation, larger SCS shows better performance.

Observation 6: Various delay spread values don’t affect the relative performance among different SCS.

###### [[14], Ericsson]

[[14, 61], Ericsson] used the following three sets of phase noise models in their evaluation:

* PN model set 1
  + BS: Ex2 BS
  + UE: Ex2 UE
* PN model set 2
  + BS: Ex2 BS
  + UE: R4-2011494 (ref R4-2011494)
* PN model set 3
  + BS: R4-2010176 DM=0 dB (ref R4-2010176)
  + UE: R4-2010176 DM=5 dB (ref R4-2010176)

The following proposal and observations are made in [14].

Proposal 9 Capture the following in TR 38.808: Link evaluation based on phase model Ex 2, with characteristics not reflecting realistic devices or current state of the technology, can lead to pessimistic assessment of smaller sub-carrier spacings. It is important for 3GPP to adopt more suitable phase noise models in the discussion and system designs for NR operation in 52.7 – 71 GHz range.

The following are observations made.

* With phase noise model set 1 using Ex 2 models at both BS and UE, BLER performance with only CPE compensation depends strongly on the SCS. It can be observed in Figure 18 that links using larger SCS outperforms those with smaller SCS. That is, links using small SCS suffer more from ICI problems caused by the time-varying phase noise. For 400 MHz bandwidth with 120 or 240 kHz SCS as well as 1.6 GHz bandwidth with 480 kHz SCS, BLER floors can be observed.
* With phase noise model set 2, the Ex 2 UE model is replaced by the new UE phase noise model provided in R4-2011494 (ref [20]). For the BS, the same Ex 2 BS model is still applied. It can be clearly observed in Figure 19 that there is significantly less dependence of BLER performance on SCS. For all test cases, no error floor is observed for smaller subcarrier spacings. Instead, there is only around 1 dB performance difference between consecutive SCSs.
* With phase noise model set 3, the BS and UE phase noise is modeled by the model provided in R4-2010176 (ref [19]) with different design margins, respectively. Similar to the cases observed in phase noise model set 2, there is significantly less dependence of BLER performance on SCS in Figure 20 than that observed in phase noise model set 1. Between consecutive SCSs, BLER performance for the same bandwidth differs by only 1 to 2 dB.
* With larger delay spreads, systems with large SCS start to suffer from inter-symbol interference (ISI). For the example of 960 kHz SCS, link performance error floor starts to develop for the 64QAM in a channel with 40 ns average delay spreads for all phase noise model sets. In contrast, for 480 kHz SCS, the performance is quite insensitive to delay spread in the range 10 – 40 ns for phase noise model sets 2 and 3.

Proposal 11 Capture the following observation in TR 38.808: Systems with smaller sub-carrier spacing equipped with simple ICI compensation is on par or better than systems with larger sub-carrier spacing equipped with only CPE compensation.

###### [[61], Ericsson]

Observation 1 Phase noise induced performance issues for the OFDM waveform in the 52.6 – 71 GHz frequency range can be effectively addressed with the Rel-15 PTRS structure and simple ICI compensation algorithms. Performance with SCS of 480 kHz with simple ICI compensation is on par or better than the performance with 960 kHz with CPE compensation only.

###### [[18], Samsung]

*Observation 1: Higher sub-carrier spacing (e.g. 960 kHz) can mitigate phase noise impact better, especially for high MSC.*

###### [[21], Apple]

*Observation 3: By using PN ICI compensation, we can reduce the maximum SCS selected when compared with CPE compensation only.*

*Observation 5: As the SCS increases, there is a trade-off between the CP required for the delay spread after beamforming (reducing the cyclic prefix and increasing the irreducible noise floor), the phase noise (reducing the PN inter-carrier interference) and the bandwidth of operation.*

*Observation 6: for higher order modulation, an increase in the SCS from 120 kHz is needed for PDSCH/PUSCH transmission.*

###### [[25], NTT DOCOMO]

Observation 1: Following observations are derived according to the link-level simulation results.

* On SCS with 400 MHz carrier bandwidth: Under the PN model and linear channel/PN estimation methods used in the evaluations, similar performance is achieved with 120 kHz and 240 kHz SCS, which is superior to remaining configurations.
* On ECP with 960 kHz SCS: BLER performance gain can be observed with ECP configuration. However, when taking ECP overhead into the consideration (14% additional overhead introduced by ECP compared with normal CP), ECP does not introduce significant throughput gain to compensate the throughput loss caused by the additional overhead.
* On PTRS & PN compensation: With 400 MHz carrier bandwidth, the BLER cannot reach 0.01 for higher MCS levels such as MCS 22, and it cannot reach 0.1 for higher MCS levels with 2 GHz carrier bandwidth. Advanced receiver and/or enhanced PTRS should be further studied to improve the link performance.

###### [[26], Qualcomm]

Observation 1: For the PDSCH performance of different numerologies in the high frequency regime, when PTRS-based phase noise correction (CPE-only) is enabled (Section 2.2.1),

* At low and medium MCSs (MCS 7 and MCS 16, respectively), no noticeable performance difference is identified among SCSs in most of the tested cases.
* At MCS 22 with 64QAM, due to the increased phase noise impact, 120kHz SCS shows up to ~1.5dB loss compared to other SCSs.
* At MCS 22 with CDL-B 50ns, 960kHz SCS shows a BLER floor at high CINR due to inter-symbol interference, but the floor is below 10%.
* The observed performance trends of different SCSs are consistent across all tested channel and antenna configurations.

###### [[64], OPPO]

Observation 1: for MCS7 and MCS16 the phase noise influence is not obvious with different SCS.

Observation 2: for MCS22, 120KHz and 240KHz cannot work properly with a simple CPE compensation but 480KHz applying ICI compensation can have comparable performance to 960KHz.

###### [[67], Charter]

Observation 1: SCS = 240 kHz is not robust against phase noise and other impairments at higher MCSs, even with ideal CPE removal.

Observation 2: SCS=960kHz is necessary to support NR PDSCH high data throughput in FR2 60GHz.

#### Summary of observations

##### Summary of observations with baseline PN model for discussion:

For CP-OFDM, in the evaluated carrier bandwidth with baseline PN model and delay spread values (i.e. < 40 ns in TDL-A), the following are observed when phase noise compensation is used.

* For low MCS (QPSK) and medium MCS (16QAM), there is minor performance difference between different SCS values up to 960KHz.
* For high MCS (64QAM), larger SCS (480 and 960 KHz) performs better than smaller SCS (120 and 240 KHz) when only CPE compensation based on the existing Rel-15 NR PT-RS structure is used.
* For high MCS (64QAM), the performance of smaller SCS (120 and/or 240 KHz) improved when ICI compensation is used in comparison to CPE compensation only.
  + Note: the following is reference when derive the observations.
  + 5 sources ([61, Ericsson], [68, Huawei], [64, OPPO], [23, MediaTek], [1, Futurewei]) evaluated and reported numerical SINR performance of SCS with ICI compensation. 2 sources ([68, Huawei], [64, OPPO]) reported comparable performance between smaller SCS (120 and/or 240 KHz) and larger SCS (480 and/or 960 KHz) when ICI compensation is used. 2 sources ([61, Ericsson], [23, MediaTek]) reported better performance of larger SCS (480 and/or 960 KHz) than smaller SCS (120 and/or 240 KHz) when ICI compensation is used. 1 source ([1, Futurewei]) reported comparable performance among SCS for low delay spread (5 and 10ns DS in TDL-A) and better performance of 120/240/480 KHz SCS than that of 960 KHz when delay spread increase (20ns DS in TDL-A and 50ns in CDL-B)
  + Another source ([26, Qualcomm]) also evaluated and compared 120 KHz SCS with ICI compensation to larger SCS with CPE compensation. It is reported that at MCSs 22 and 24, 120kHz SCS with ICI compensation performs almost equal to 960kHz SCS with CPE-only compensation. It also reported that at MCS 26, 120kHz SCS with ICI compensation suffers from residual ICI and is outperformed by 960kHz SCS with CPE-only compensation.
  + Another source ([18, Samsung]) evaluated 120 KHz and 240 KHz SCS performance with ICI compensation based on some new PTRS pattern and reported performance improvement.
  + Another source ([65, Apple]) evaluated ICI compensation for different SCS with a new PTRS pattern. It report improvement of ICI compensation compared to CPE-only compensation. It also reported that the performance of 960 KHz SCS with CPE-only compensation is still better 120 and 240 KHz SCS with ICI compensation.
* For high MCS (64QAM), when only CPE compensation based on the existing Rel-15 NR PT-RS structure is used, 14 sources ([61, Ericsson], [68, Huawei], [26, Qualcomm], [56, vivo], [60, ZTE], [64, OPPO], [10, Nokia], [2, 55, Lenovo], [21, Apple], [18, Samsung], [25, NTT DOCOMO], [12, Intel], [67, Charter], [7, InterDigital]) compared performance of 480 and 960 KHz SCS
  + for 10% BLER target, there is a performance gap between 480kHz and 960kHz SCS where 960 KHz performs better.
    - Note: the following is reference when derive the observations.
    - 8 sources ([61, Ericsson], [68, Huawei], [60, ZTE], [64, OPPO], [10, Nokia], [2, 55, Lenovo], [67, Charter], [7, InterDigital]) reported a greater than 1 dB gain of 960 KHz, 4 sources ([26, Qualcomm], [56, vivo], [18, Samsung], [25, NTT DOCOMO]) reported comparable performance (< 1 dB difference), 2 source ([21, Apple], [12, Intel]) reported comparable performance for low delay spread (5 and 10 ns DS in TDL-A) while a better performance of 480 KHz than 960 KHz at medium delay spread (20ns DS in TDL-A).
  + for 1% BLER target, the performance for 960kHz is better than 480kHz.
    - Among sources reported SINR values for 1% BLER target, the absolute value of the performance gap between 480kHz and 960kHz is larger than that for 10% BLER target.

Companies are encouraged to provide comments to the above proposal.

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

##### Observations on evaluations with different PN model(s):

During the GTW session, there’s a comment to capture observations on different phase noise model evaluation. To the best knowledge of moderator, there’s one company submitted evaluation results with different PN models (in addition to baseline PN model) in [[14, 61], Ericsson].

There’s only one explicit proposal/observation (proposal 9 in [14] quoted below) made related to different PN model.

###### [[14], Ericsson]

Proposal 9 Capture the following in TR 38.808: Link evaluation based on phase model Ex 2, with characteristics not reflecting realistic devices or current state of the technology, can lead to pessimistic assessment of smaller sub-carrier spacings. It is important for 3GPP to adopt more suitable phase noise models in the discussion and system designs for NR operation in 52.7 – 71 GHz range.

Companies are encouraged to provide comments.

|  |  |
| --- | --- |
| Company Name | Comments/Views |
| Moderator | A question to the companies who propose to capture observations on different phase noise model evaluation, is the above proposal 9 in [14] the one to be captured as the observation on evaluations of different PN model? If not, please state which observation/proposal in which submitted contributions is the observation(s) you are referring to be captured? |
| Moderator 2 | On the email reflector, Ericsson clarified to capture some observations in section 3.3.1 of [14] (copied below) which are not in the list of observations in the conclusion section of [14].  The following are observations made in [14].   * With phase noise model set 1 using Ex 2 models at both BS and UE, BLER performance with only CPE compensation depends strongly on the SCS. It can be observed in Figure 18 that links using larger SCS outperforms those with smaller SCS. That is, links using small SCS suffer more from ICI problems caused by the time-varying phase noise. For 400 MHz bandwidth with 120 or 240 kHz SCS as well as 1.6 GHz bandwidth with 480 kHz SCS, BLER floors can be observed. * With phase noise model set 2, the Ex 2 UE model is replaced by the new UE phase noise model provided in R4-2011494 (ref [20]). For the BS, the same Ex 2 BS model is still applied. It can be clearly observed in Figure 19 that there is significantly less dependence of BLER performance on SCS. For all test cases, no error floor is observed for smaller subcarrier spacings. Instead, there is only around 1 dB performance difference between consecutive SCSs. * With phase noise model set 3, the BS and UE phase noise is modeled by the model provided in R4-2010176 (ref [19]) with different design margins, respectively. Similar to the cases observed in phase noise model set 2, there is significantly less dependence of BLER performance on SCS in Figure 20 than that observed in phase noise model set 1. Between consecutive SCSs, BLER performance for the same bandwidth differs by only 1 to 2 dB. * With larger delay spreads, systems with large SCS start to suffer from inter-symbol interference (ISI). For the example of 960 kHz SCS, link performance error floor starts to develop for the 64QAM in a channel with 40 ns average delay spreads for all phase noise model sets. In contrast, for 480 kHz SCS, the performance is quite insensitive to delay spread in the range 10 – 40 ns for phase noise model sets 2 and 3.   A summary observation is formulated. |

##### Summary of observations with optional PN model for discussion:

For CP-OFDM, one source ([14, 60], Ericsson) evaluated PDSCH BLER performance with optional PN model in addition to baseline PN model. The following are observed when phase noise compensation is used.

* For baseline PN model, it is observed that BLER performance with only CPE compensation depends strongly on the SCS. Larger SCS outperforms smaller SCS since small SCS suffer more from ICI problems caused by the time-varying phase noise.
* When an optional PN model is used at the UE or at BS and UE, there is significantly less dependence of BLER performance on SCS. For all test cases, no error floor is observed for smaller SCS. There is around 1 to 2 dB performance difference between consecutive SCSs.
* With larger delay spreads, 960 kHz SCS has error floor for 64QAM in TDL-A with 40 ns DS for all evaluated phase noise models.

Companies are encouraged to provide comments to the above proposal.

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### Large delay spread and CP impact

#### Delay spread distribution

There’re multiple sources discussed delay spread distribution and reported delay spread distribution based on system level evaluation.

The following are observations and/or statements directly extracted from these sources.

###### [[7], InterDigital]

It shows the CDF of RMS delay spread for Indoor Factory B, Indoor Office C and Outdoor C based on the system level simulations with the agreed evaluation assumptions. The following observation is made.

Observation 4: While each scenario experiences different amounts of RMS delay spread, regardless of scenarios, most of UEs experience smaller RMS delay spreads than normal CP of 960 kHz.

###### [[12], Intel]

It shows the effective channel delay spread statistics observed on system-level simulation results. Note that the delay spread calculation takes Tx and Rx beamforming into account, i.e. it is the actual delay spread the receiver observes, not a general characteristic of a channel model multipath.

Observation 1

* *There is negligible difference between 60GHz and 70GHz RMS delay spread statistics for antenna arrays of 64 elements and larger.*

Observation 2

* *RMS delay spread significantly depends on Tx and Rx beamwidth.*

Observation 3

* *RMS delay spread in LoS links is 1 – 2 orders of magnitude smaller than in NLoS links.*

Observation 4

* *85% of UEs experience RMS delay spread smaller than SCS 1.92MHz CP length (36.6 ns).*

###### [[14], Ericsson]

It is observed that the 90th percentile RMS delay spread (45.2 ns) is a significant fraction of the CP duration for 960 kHz SCS (73.2 ns) and made the following proposal.

Proposal 8 Capture the following observation in TR 38.808. Factory Scenario A (InF-DH) results in post-beamforming delay spreads that are a significant fraction of the CP duration for 960 kHz SCS.

###### [[25], NTT DOCOMO]

It reported the distribution of RMS delay spread (DS) of the channel for those UEs whose RSRP is larger than the specified threshold for outdoor-B scenario and made the following observation.

Observation 8:

* *The mean RMS DS of 60 GHz system in Outdoor-B scenario is about 23 ns and the 95%-tile DS value is about 80 ns.*
  + *More than half of UE experiences channels with DS larger than 20 ns, which should be referred to in the link performance evaluation with large DS configurations.*

###### [[56], vivo]

It is observed that the DS of almost 80% users are less than 30ns in a typical indoor scenario (indoor-A).

##### Moderator’s comment

Delay spread distribution was agreed to be a secondary metric for SLS. It is moderator’s understanding that observations based on SLS in general including delay spread distribution for different scenarios would be in the scope of another discussion on SLS related issues.

Companies are encouraged to provide comments if any.

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#### Large delay spread and CP type

Multiple sources evaluated the impact of CP type on the BLER performance with TDL-A and/or CDL channel model with large delay spread.

The following are observations directly extracted from these sources.

###### [[1], Futurewei]

It evaluated 120, 240, 480 and 960 KHz SCS with ICI filter to cancel the PN impact. The optimal number of taps for ICI filter is decided to be {1,3,5,7} FD filter taps for {960 kHz, 480kHz, 240 kHz, 120 kHz} SCS respectively, where 1-tap filter is equivalent to CPE compensation. The following observations are made.

Observation 5: Lower SCS {120 kHz, 240 kHz} offer better performance at higher DS. The BLER for SCS 960kHz, MCS16, and Normal CP is not acceptable for 40ns DS.

Observation 6: For 20ns DS, MCS 22, NCP, the BLER for 960 kHz SCS is not acceptable, while {120kHz, 240kHz and 480 kHz} SCS offer similar and acceptable performance.

Observation 7: The extended CP improves BLER performances, for 480 kHz and 960 kHz SCS for larger DS, MCS 22 [Figures 8-10 in [1]] with a reduction in spectrum efficiency of 14% (from 14 symbols to 12 symbols slots).

Observation 8: CDL channel models simulations show for larger DS and higher MCS SCS 120kHz, 240kHz and 480 kHz offer similar good performances.

###### [[2], Lenovo]

Observation 6: For 400MHz BW, when higher delay spread value such as 40ns is simulated for SCS values up to 960kHz, it can be observed that the BLER is significantly improved for 960kHz with extended CP and it performs best in terms of BLER, however, the effective throughput is compromised due to larger overhead of extended CP and therefore, 480kHz with normal CP performs best in terms of throughput.

Observation 7: For 2GHz BW, when higher delay spread value such as 20ns is simulated for SCS values of 960kHz and 1920kHz, it can be observed that the BLER is significantly improved for 1920kHz with extended CP and it performs best in terms of BLER, however, the effective throughput is compromised due to larger overhead of extended CP and therefore, 960kHz with normal CP performs best in terms of throughput.

###### [[55], Lenovo]

It evaluated PDSCH with different SCS values including 120kHz, 240kHz, 480kHz, 960kHz and 1920MHz with different MCS values including MCS7 (QPSK), MCS16 (16QAM) and MCS22 (64QAM) in CDL channel. The following observations are made.

Observation 3: For higher delay spread and normal cyclic prefix, 960kHz subcarrier spacing performs the worst and target BLER cannot be reached for high MCS

Observation 4: For higher delay spread and extended cyclic prefix, 960kHz subcarrier spacing performance is significantly improved compared to normal cyclic prefix

Observation 7: For higher delay spread and normal cyclic prefix, 960kHz subcarrier spacing performs the worst

Observation 8: For higher delay spread and extended cyclic prefix, 960kHz subcarrier spacing performance is significantly improved compared to normal cyclic prefix and it performs slightly better than 480kHz for high MCS

###### [[3], Huawei]

Observation 3: In CDL-B with DS=50ns, the NCP length of SCS 960 kHz is not sufficient to cover the delay spread. If 480 kHz or 960 kHz were supported, ECP would be required in order to accommodate the delay spread, time alignment error, analog beam switching time, DL/UL switching time, and Multi-TRP delay; causing a larger overhead.

###### [[68], Huawei]

Observation 2: If CDL-B DS=50ns channel model is considered, the BLER performance of a subcarrier spacing larger than 480 kHz decreases a lot due to the short CP length.

###### [[5], vivo]

Observation 6: (120K, NCP) and (240K, NCP) have better coverage than other candidate numerologies.

Observation 7: ECP doesn’t offer better coverage than NCP for both 480K and 960K SCS in TDL-A channel with delay spread setting as 5, 10, 20 and 40 ns.

###### [[56], vivo]

Observation 1: Under the same DS, the performance of NCP is basically the same as ECP for CP-OFDM waveform.

###### [[12], Intel]

Observation 9:

* *There is marginal performance improvement from the use of ECP observed only for 64QAM and SCS=1920kHz.*
* *There is almost no difference between ECP and NCP for 16QAM when SCS=960kHz or SCS=1920kHz for the tested delay spread values.*

###### [[14], Ericsson]

Proposal 12 Capture the following observation in TR 38.808: 960 kHz SCS ECP MCS 22 performs worse than 480 kHz SCS NCP MCS 22 even for allowing lower data rates carried by ECP. On an equal data rate basis, 480 kHz SCS NCP MCS 22 is more than 6 dB better than 960 kHz SCS ECP MCS 25.

###### [[25], NTT DOCOMO]

Observation 1: *Following observations are derived according to the link-level simulation results.*

* *On SCS with 400 MHz carrier bandwidth: Under the PN model and linear channel/PN estimation methods used in the evaluations, similar performance is achieved with 120 kHz and 240 kHz SCS, which is superior to remaining configurations.*
* *On ECP with 960 kHz SCS: BLER performance gain can be observed with ECP configuration. However, when taking ECP overhead into the consideration (14% additional overhead introduced by ECP compared with normal CP), ECP does not introduce significant throughput gain to compensate the throughput loss caused by the additional overhead.*
* *On PTRS & PN compensation: With 400 MHz carrier bandwidth, the BLER cannot reach 0.01 for higher MCS levels such as MCS 22, and it cannot reach 0.1 for higher MCS levels with 2 GHz carrier bandwidth. Advanced receiver and/or enhanced PTRS should be further studied to improve the link performance.*

###### [[26], Qualcomm]

It was observed that 960kHz SCS can sustain pre-beamforming RMS channel delay spread up to 100ns with some moderate performance loss at high MCSs.

##### Summary of observations for discussion:

For CP-OFDM, in the evaluated carrier bandwidth with baseline PN model, the following are observed.

* When delay spread is not large (< 40 ns in TDL-A), there is minor performance difference between normal and extended CP for SCS values up to 960 KHz.
* Among 11 sources ([61, Ericsson], [68, Huawei], [26, Qualcomm], [56, vivo], [60, ZTE], [64, OPPO], [2, 55, Lenovo], [1, Futurewei], [25, NTT DOCOMO], [12, Intel], [7, InterDigital]) evaluated with large delay spread (i.e. 40 ns in TDL-A and/or 50ns in CDL), 10 sources observed that for low MCS (QPSK) and medium MCS (16QAM), there is minor performance difference between different SCS values up to 960KHz for BLER target 10%.
  + The other source ([1, Futurewei]) evaluated SCS 960 KHz with 1-tap ICI filter at MCS16 with normal CP in TDL-A channel with 40ns DS. It reported that the BLER for SCS 960kHz, MCS16, and Normal CP is not acceptable (cannot meet 10% BLER target) for 40ns DS.
* 10 sources ([61, Ericsson], [68, Huawei], [26, Qualcomm], [56, vivo], [60, ZTE], [64, OPPO], [2, 55, Lenovo], [25, NTT DOCOMO], [12, Intel], [7, InterDigital]) evaluated large delay spread (i.e. 40 ns in TDL-A and/or 50ns in CDL) with CPE compensation based on the existing Rel-15 NR PT-RS structure with normal CP. Among 10 sources, 4 sources ([14, Ericsson], [56, vivo], [2, 55, Lenovo], [25, NTT DOCOMO]) also evaluated extended CP at least for 960 KHz SCS with CPE compensation based on the existing Rel-15 NR PT-RS structure.
  + 9 out 10 sources observed that for high MCS (64QAM) with normal CP, larger SCS (480 and 960 KHz) performs better than smaller SCS (120 and 240 KHz) when only CPE compensation based on the existing Rel-15 NR PT-RS structure is used. The other source ([25, NTT DOCOMO]) reported better performance of smaller SCS.
  + 4 out 4 sources observed the performance of 960KHz SCS with extended CP is significantly improved compared to with normal CP for large delay spread case. However, the effective throughput is compromised due to larger overhead of extended CP.
* For high MCS (64QAM) with normal CP, 4 sources evaluated large delay spread (CDL-B with 50ns) with ICI compensation.
  + One source ([61, Ericsson]) reported SCS 480 and 960 kHz offer similar performances, which are better than those of smaller SCS (120 and 240 KHz).
  + One source ([68, Huawei]) reported similar performances for 120, 240 and 480 KHz SCS, and they are better than that of 960 KHz.
  + One source ([1, Futurewei]) report similar performance for 120, 240 and 480 KHz. It also reported the BLER for 960 kHz SCS is not acceptable.
  + One source ([64, OPPO]) reported similar performances of 240 and 480 KHz SCS, and they are better than that of 960 KHz. It also reported the performance of 120 KHz cannot meet the 10% BLER target.

Companies are encouraged to provide comments to the above proposal.

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### DFT-s-OFDM PUSCH

Multiple sources evaluated the BLER performance of DFT-s-OFDM PUSCH with TDL-A and/or CDL channel model. The following are observations directly extracted from these sources.

###### [[3], Huawei]

Observation 2: For DFT-s-OFDM, when the PTRS pattern defined in R15 for DFT-s-OFDM is used, SCS of 240 kHz can achieve similar PUSCH BLER as 480 kHz or 960 kHz for QPSK, 16QAM and 64QAM. Sample density of 8 PTRS groups and 4 PTRS samples per group is not suitable for 120 kHz SCS with 400 MHz scheduled bandwidth for 64QAM.

###### [[68], Huawei]

Observation 4: Simulation results for DFT-s-OFDM show that, SCSs larger than 240 kHz do not achieve a better BLER performance than 120 and 240 kHz SCSs for QPSK and 16QAM. BLER performance of 120 kHz for 64QAM reaches a floor above 10-2 due to a lower overhead of PTRS and the longest interpolation range.

###### [[10], Nokia]

Observation 9: DFT-s-OFDM is more robust under phase noise than CP-OFDM, and can enable use of smaller SCS with significantly smaller PTRS overhead. Even 120kHz can be supported for 64-QAM.

###### [[14, 61], Ericsson]

Observation 2 Phase noise induced performance issues for the DFT-s-OFDM waveform in the 52.6 – 71 GHz frequency range can be addressed with the Rel-15 uplink PTRS structure and currently supported SCS values, e.g., 120 kHz.

###### [[26], Qualcomm]

Observation 2: For the PUSCH (DFT-s-OFDM) performance of different numerologies in the high frequency regime, when PTRS-based phase noise correction is enabled (Section 2.2.2 in [26]),

* At low and medium MCSs (MCS 7 and MCS 16, respectively), no noticeable performance difference is identified among SCSs in most of the tested cases.
* At MCS 22 with 64QAM, due to the increased phase noise impact, 120kHz SCS shows up to ~2.0dB loss compared to other SCSs.
* At MCS 22, the performance is slightly degraded as the bandwidth increases due to the residual inter-time-domain-sample interference after the frequency-domain equalization.
* At MCS 22 with CDL-B 50ns, 960kHz SCS shows a BLER floor at high CINR due to inter-symbol interference, but the floor is below 10%.
* The observed performance trends of different SCSs are consistent across all tested channel and antenna configurations.

###### [[56], vivo]

Observation 6: For 400MHz bandwidth, compared with CP-OFDM waveform, the PN compensation of DFT-S-OFDM waveform can eliminate the influence of PN more effectively, especially for the small SCS (120KHz and 240KHz).

Observation 7: For DFT-S-OFDM waveform, under the same PTRS overhead, the more PTRS number, the better the BLER performance.

Observation 8: For DFT-S-OFDM waveform, with the increase of DS (≤20ns), the performance of higher SCS will slightly deteriorate. When the DS increase to 40ns, the SCS 960 has significant performance loss.

Observation 9: For DFT-S-OFDM waveform, larger bandwidth (more RB numbers) is more sensitive to PN impact.

##### Summary of observations for discussion:

7 sources ([61, Ericsson], [68, Huawei], [26, Qualcomm], [56, vivo], [64, OPPO], [10, Nokia], [21, Apple]) evaluated DFT-S-OFDM PUSCH BLER performance with different SCS. Note that [10, Nokia] does not report numerical SINR results in table but provided figures only.

* Compared to CP-OFDM, DFT-s-OFDM is more robust under phase noise when PTRS-based phase noise compensation is enabled.
  + For low and medium MCSs (QPSK and 16QAM), there’s minor performance difference among evaluated SCSs up to 960KHz.
  + With normal CP, for high MCS (64QAM), the performance improves as the increase of SCS, 120kHz SCS shows up to ~2.0dB loss compared to other larger SCS.
    - Note: the following are references when derive the observations.
    - [61, Ericsson] reported a performance gap of 1.4~1.8 dB between 120 and 960 KHz
    - [68, Huawei] reported a performance gap of 1.3~2.5 dB between 120 and 960 KHz
    - [26, Qualcomm] reported a performance gap of 1.2~1.7 dB between 120 and 960 KHz
    - [56, vivo] reported a performance gap of ~1.4 dB between 120 and 960 KHz
    - [21, Apple] reported a performance gap of more than 7 dB performance gap between 120 and other SCS (240, 480 and 960 KHz) at TDL-A 5 ns. It also reported 120 KHz SCS cannot meet the BLER target of 10% at TDL-A 10ns and 960 KHz cannot meet the BLER target of 10% at TDL-A 20ns.
    - [64, OPPO] reported 120 and 240 KHz cannot meet the BLER target of 10% for all evaluated DS values
  + For high MCS (64QAM) at large delay spread (TDL-A 40ns or CDL-B 50ns DS), there’s error floor for 960 KHz SCS at least for BLER target 1%.
    - Note: the following are reference when derive the observations.
    - [26, Qualcomm] reported an error floor for 960 KHz SCS for BLER target 1%.
    - [56, vivo] reported an error floor for 960 KHz SCS for BLER target 10%
    - [64, OPPO] reported no error floor of 960 KHz SCS for the BLER target of 10% and 1% for CDL-B 50ns but an error floor for 960 KHz SCS at TDL-A 20ns for BLER target 1%

Companies are encouraged to provide comments to the above proposal.

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### ICI and PTRS impact

Multiple sources evaluated the BLER performance with respect different phase noise compensation methods (e.g. PTRS based CPE, ICI) and different PTRS configurations.

The following are observations directly extracted from these sources regarding ICI, PTRS-based CPE impact.

###### [[1], Futurewei]

It evaluated 120, 240, 480 and 960 KHz SCS with ICI filter to cancel the PN impact. The optimal number of taps for ICI filter is decided to be {1,3,5,7} FD filter taps for {960 kHz, 480kHz, 240 kHz, 120 kHz} SCS respectively, where 1-tap filter is equivalent to CPE compensation. The following observations are made.

Observation 3: With the ICI filter, all analyzed SCS provide similar performance for DS=10ns at the cost of additional signal processing required by the ICI filtering.

Observation 4: The filtering operation for ICI cancelation consists of convolution in the frequency domain between the filter and data subcarriers for each symbol.

###### [[2], Lenovo]

It evaluated no phase noise compensation and PT-RS based phase noise compensation (CPE) for different values of MCS. The following observations are made.

Observation 8: For lower MCS range with QPSK modulation, there is almost no performance gain with phase noise compensation, while slight gain can be observed for mid-range MCS with 16QAM and significant gain is observed for high MCS with 64QAM for all the SCS values.

Observation 9: For higher SCS values, simply increasing the density of PT-RS in frequency domain doesn’t improve the throughput performance in comparison to lower density of PT-RS resources in frequency domain.

###### [[10], Nokia]

With ICI compensation, it’s observed:

*Observation 5: Both 960 kHz SCS and 480 kHz SCS provide robust performance with ICI compensation. However, for a wideband scenario (which is the main use case for a high SCS), 960 kHz SCS provides up-to 0.8 dB gain compared to 480 kHz SCS.*

*Observation 7: ICI cancellation enables 120kHz SCS for at least up to 64-QAM.*

###### [[11], Mitsubishi]

Note the evaluation is done for a 500 MHz BW.

Observation 2: *Around Fc=60GHz, SCS=120kHz and with 16QAM 2/3, block-based PT-RS with cyclic sequence is able of matching the FER performance of the Rel.15 pattern with de-ICI Wiener filtering with a significantly lower overhead (up to 3 times less in some of the simulated scenarios).*

Observation 3: *For Fc=60GHz and SCS=120kHz, the PN compensation with block-based PT-RS and cyclic sequence significantly outperforms in spectral efficiency both CPE compensation and de-ICI Wiener filtering with distributed PT-RS, even when the density of the scattered pattern is increased above the Rel.15 defined density.*

Observation 4: *For Fc=70GHz and SCS=120kHz, the CPE compensation with distributed PT-RS does not reach FER=0.1 whereas the PN compensation with block-based PT-RS and cyclic sequence reaches significantly outperforms de-ICI Wiener filtering.*

Observation 5: *For Fc=70GHz and SCS=240kHz, the PN compensation with block-based PT-RS and cyclic sequence significantly outperforms both the de-ICI Wiener filtering and the CPE compensation.*

###### [[12], Intel]

Observation 11

* *Advanced phase noise compensation methods, such as direct de-ICI compensation method, may not be suitable for NR operating in 52.6 GHz to 71 GHz.*

###### [[14], Ericsson]

Evaluated with 400 and 1600 MHz BW.

Proposal 10 Capture the following observation in TR 38.808: Effective mitigation of ICI caused by phase noises for OFDM can be performed using the existing Rel-15 NR distributed PT-RS structure.

Proposal 11 Capture the following observation in TR 38.808: Systems with smaller sub-carrier spacing equipped with simple ICI compensation is on par or better than systems with larger sub-carrier spacing equipped with only CPE compensation.

Proposal 40 Capture the following observation in TR 38.808: A clustered PT-RS structure does not offer any performance advantage over the existing Rel-15 NR distributed PT-RS structure.

###### [[18], Samsung]

Observation 4: ICI compensation has performance gain over CPE compensation.

Observation 5: Performance with the new PT-RS pattern (e.g. chunk based PT-RS pattern) is better than the Rel-15 pattern since it enables ICI compensation in addition to CPE compensation.

###### [[19], OPPO]

Observation 8: with legacy PTRS pattern, phase noise impact is more visible for MCS 22.

Observation 9: the ICI compensation can further reduce the BLER floor compared with simple CPE compensation, but displays a 2~2.5 dB gap to phase noise off performance.

###### [[23], MediaTek]

Observation 1: A simple, 3-tap BLS ICI equalizer is able to eliminate the error floor caused by the ICI, and in turn allows proper operation using current NR numerology (e.g., SCS = 120KHz).

Observation 2: When 3-tap BLS ICI equalizer is used at the receiver, R-15 PTRS design and block PTRS design offer identical performance.

Observation 3: More complicated ICI equalization technique (e.g., DFE), together with the block PTRS design, may further reduce the performance degradation due to phase noise.

###### [[25], NTT DOCOMO]

Observation 1: Following observations are derived according to the link-level simulation results.

* On SCS with 400 MHz carrier bandwidth: Under the PN model and linear channel/PN estimation methods used in the evaluations, similar performance is achieved with 120 kHz and 240 kHz SCS, which is superior to remaining configurations.
* On ECP with 960 kHz SCS: BLER performance gain can be observed with ECP configuration. However, when taking ECP overhead into the consideration (14% additional overhead introduced by ECP compared with normal CP), ECP does not introduce significant throughput gain to compensate the throughput loss caused by the additional overhead.
* On PTRS & PN compensation: With 400 MHz carrier bandwidth, the BLER cannot reach 0.01 for higher MCS levels such as MCS 22, and it cannot reach 0.1 for higher MCS levels with 2 GHz carrier bandwidth. Advanced receiver and/or enhanced PTRS should be further studied to improve the link performance.

###### [[26], Qualcomm]

Observation 6: 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.

Observation 7: 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.
  + 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 8: 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.

###### [[57], InterDigital]

*Observation 2: Increased PT-RS density in frequency domain based on Rel-15 configuration does not provide significant performance benefits.*

###### [[62], LG]

Observation #1: Performance improvement that can be acquired from ICI compensation schemes is negligible for higher SCS.

Observation #2: The performance of clustered PTRS allocation is worse than that of Rel-15 PT-RS based ICI compensation scheme.

Observation #3: The performance of subcarrier nulling allocation is similar or superior (up to 2 dB gain especially in the scenarios with low PTRS overhead, K=4) to that of Rel-15 PT-RS based ICI compensation scheme.

###### [[65], Apple]

*Observation 1: Modifying the PTRS pattern to allow adjacent PTRS symbols in frequency with an ICI compensation filter gives better performance at a lower SCS than the existing Rel-15 PTRS pattern with CPE compensation only.*

##### Summary of observations for discussion:

For CP-OFDM, in the evaluated carrier bandwidth with baseline PN model, the following are observed.

* For PTRS based CPE, phase noise compensation shows little gain at low and medium MCSs for all the evaluated SCS values. While significant gain is observed for high MCS (64QAM) for all the evaluated SCS values.
  + One source ([57, InterDigital]) reported that increased PT-RS density in frequency domain based on Rel-15 configuration does not provide significant performance benefits.
* Multiple sources evaluated ICI compensation schemes using the existing Rel-15 NR distributed PTRS structure and new PTRS patterns. Performance gain of ICI compensation compared to no ICI compensation is observed for smaller SCS (e.g., 120 and 240 KHz) and high MCS.
  + Note: the following is reference when derive the observations.
  + One source ([12, Intel]) evaluated performance of de-ICI method for MCS 22 with small RB allocations for 240, 480 and 960 KHz SCS. It is observed that the de-ICI method do not work when there isn’t sufficient number of PTRS tones in the frequency domain. It also evaluated the phase noise compensation performance with MCS 28. It is observed that while CPE technique work well for these high SNR regions, de-ICI technique with smaller subcarrier spacing fails even though there are sufficient number of PTRS tones available for ICI covariance construction.
  + One source ([11, Mitsubishi]) evaluated with 120 KHz SCS and reported that the PN compensation with block-based PT-RS and cyclic sequence significantly outperforms in spectral efficiency both CPE compensation and de-ICI Wiener filtering with distributed PT-RS, even when the density of the scattered pattern is increased above the Rel.15 defined density.
  + Two sources ([14, Ericsson] with Direct de-ICI compensation and ICI filter approximation, [23, MediaTek] with a 3-tap BLS ICI equalizer) reported a clustered PT-RS structure does not offer any performance advantage over the existing Rel-15 NR distributed PT-RS structure.
  + One source ([62, LG]) reported that the performance of clustered PTRS allocation is worse than that of Rel-15 PT-RS based ICI compensation scheme and further showed that the performance of subcarrier nulling allocation is similar or superior (up to 2 dB gain especially in the scenarios with low PTRS overhead, K=4) to that of Rel-15 PT-RS based ICI compensation scheme.
  + Two sources ([18, Samsung], [65, Apple]) evaluated the performance with some new PT-RS patterns (e.g. chunk based PT-RS pattern to allow adjacent PTRS symbols in frequency) and reported that the performance with ICI compensation based on new PT-RS patterns is better than the Rel-15 pattern with CPE compensation only.
  + One source ([26, Qualcomm]) reported that for the same ICI compensation algorithm, the legacy PTRS pattern outperforms the block PTRS pattern. It showed that 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). The same source compared the performance of CPE and ICI compensation and reported for MCSs 22 and 24, 120kHz SCS with ICI compensation performs almost equal to 960kHz SCS with CPE-only compensation; while for MCS 26, 120kHz SCS with ICI compensation suffers from residual ICI and is outperformed by 960kHz SCS with CPE-only compensation.

Companies are encouraged to provide comments to the above proposal.

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### DMRS impact

Multiple sources submitted evaluation results impact on DMRS based on the agreed LLS evaluation assumptions. The following are observations directly extracted from these sources.

###### [[2], Lenovo]

It evaluated the performance for higher SCS values between front-loaded DMRS type 1 and with ideal channel estimation to show the impact of different SCS values on DM-RS based channel estimation performance for both 400MHz and 2GHz bandwidth. The following observations are made.

Observation 10: 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.

###### [[7], InterDigital]

*Observation 5: The performance loss from channel estimation error gets reduced as DM-RS density increases especially when a higher modulation order is used.*

###### [[57], InterDigital]

*Observation 1: Increased number of DM-RS symbols mitigates performance degradation from the channel estimation error and the RF impairments especially for higher modulation order and smaller bandwidth.*

###### [[12], Intel]

Proposal 6

* *For subcarrier spacing 480 kHz and 960 kHz, PDSCH (and potentially PUSCH) reception performance is impacted by frequency domain OCC in DMRS, and therefore we suggest that RAN1 further investigate on frequency domain OCC for DMRS.*

###### [[14], Ericsson]

Proposal 42 Capture the following observation in TR 38.808. For 480 kHz SCS and below with large delay spread, the room for performance improvement with a change to the Rel-15 DMRS design is very limited.

###### [[26], Qualcomm]

“Due to the poor interpolation and loss of orthogonality among CDMed DMRS ports, the performance loss are significant, especially when the CDM is enabled and the channel delay spread is large.”

###### [[66], NTT DOCOMO]

**Observation 1:** *Extended SCS of NR on 52.6 GHz to 71 GHz is comparable with coherent bandwidth for typical scenarios on 70 GHz band, which causes performance loss for DMRS based channel estimation with DMRS structure specified in Rel-15 NR.*

* *FDM (incl. comb) and FD-OCC may introduce severe performance loss in such conditions.*

##### Summary of observations for discussion:

* One source ([57, InterDigital]) reported performance improvement with increased number of DMRS symbols or increased DMRS density especially for higher modulation order.
* One source ([14, Ericsson]) reported for 480 kHz SCS and below with large delay spread, the room for performance improvement with a change to the Rel-15 DMRS design is very limited.
* One source ([12, Intel]) reported a performance drop when frequency domain OCC is enabled especially for higher order modulation such as 64 QAM (MCS 22). The performance gap increases when channel delay spread increases.
* One source ([26, Qualcomm]) reported performance improvement with a new DMRS pattern featured by high frequency density (i.e., every RE) and 2-FD-OCC across adjacent REs.

Companies are encouraged to provide comments to the above proposal.

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## 2.2. SSB performance

Multiple sources submitted evaluation results on SSB performance based on the agreed LLS evaluation assumptions.

The following are observations directly extracted from these sources regarding SSB and PBCH performance.

###### [[19], OPPO]

Observation 1: From the SSB detection simulation, the FR2 SCS has comparable performance to 480KHz or 960KHz. Phase noise and mobility are not critical issue for FR2 SCS based SSB.

###### [[21], Apple]

*Observation 8: As expected, the PBCH BLER performance difference between 240 kHz, 480 kHz and 960 kHz is less than 0.5 dB.*

###### [[25], NTT DOCOMO]

Observation 2:

* *For SS detection, PBCH DMRS detection and PBCH BLER performances, all candidate SCSs show comparable performances in TDL channel.*

###### [[26], Qualcomm]

Observation 3: For the PSS and SSS detection performance of different numerologies in the high frequency regime (Section 2.2.3 in [26]),

* The performance is degraded as the SCS increases due to the enhanced frequency selectivity.
  + The impact is more pronounced in NLOS channels (i.e., CDL-B and TDL-A) with larger delay spreads: ~2dB loss for 960kHz SCS compared to 120kHz SCS.
  + Antenna Config 2 is more sensitive as the post-beamforming delay spread is likely to be larger than Config 1.

Observation 4: For the PBCH performance of different numerologies in the high frequency regime (Section 2.2.4 in [26]),

* The performance is degraded as the SCS increases due to the enhanced frequency selectivity.
  + The impact is more pronounced in NLOS channels (i.e., CDL-B and TDL-A) with larger delay spreads: ~1.7dB loss for 960kHz SCS compared to 120kHz SCS.
  + Antenna Config 2 is more sensitive as the post-beamforming delay spread is likely to be larger than Config 1.

###### [[56], vivo]

Observation 10: For SSB detection, when the coarse frequency offset searcher range equals to the fine frequency offset compensation value, higher SCS (larger bandwidth) shows better performance.

Observation 11: For SSB channel, CP length and SCS will affect the autocorrelation of PSS sequence, thereby affecting the SSB detection performance.

Observation 12: For Cell ID detection, when the coarse frequency offset searcher range equals to the fine frequency offset compensation value, various SCS and DS have little effect on the cell ID BLER performance.

##### Summary of observations for discussion:

7 sources ([61, Ericsson], [26, Qualcomm], [56, vivo], [64, OPPO], [21, Apple], [25, NTT DOCOMO], [12, Intel]) reported evaluation results of PSS/SSS detection performance in terms of SINR in dB achieving cell ID detection probability of 90% by one-shot detection from PSS/SSS. 4 sources ([61, Ericsson], [26, Qualcomm], [56, vivo], [21, Apple]) reported PBCH performance in terms of SINR in dB achieving PBCH BLER target of 10%. The following are observed.

* For PSS and SSS detection performance, all evaluated candidate SCSs (120, 240, 480 and 960 KHz) show comparable performances with the baseline channel models and delay spread values.
  + The performance degrades as the increase of SCS.
  + Note: the following is reference when derive the observations.
  + 6 out of 7 sources reported minor performance difference (< or ~ 1 dB) between adjacent SCS for all evaluated candidate SCSs (120, 240, 480 and 960 KHz). The other source ([21, Apple]) reported more than 3 dB performance gap of 960 KHz SCS compared to other 120, 240 and 480KHz SCS. It also reported that the gap of 960 KHz increases as the delay spread increases.
* For PBCH BLER performance, all evaluated candidate SCSs (120, 240, 480 and 960 KHz) show comparable performances with the baseline channel models and delay spread.
  + The performance degrades as the increase of SCS.
  + All 4 sources reported minor performance difference (< or ~ 1 dB) between adjacent SCS for all evaluated candidate SCSs (120, 240, 480 and 960 KHz).
  + The performance gap between 120 and 960 KHz is up to ~ 1.8 dB.

Companies are encouraged to provide comments to the above proposal.

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## 2.3. PRACH performance

Multiple sources submitted evaluation results on PRACH detection performance based on the agreed LLS evaluation assumptions.

The following are observations directly extracted from these sources.

###### [[68], Huawei]

*Observation 5: The detection performance gap between 960 kHz and 120 kHz is about 1.3dB under CDL-B, and the detection performances for different SCSs are almost the same under CDL-D.*

###### [[13, 60], ZTE]

Observation 7: Phase noise and delay spread have limited impact on PRACH performance, the performance of SCS 120 kHz, 240 kHz, 480 kHz and 960 kHz is similar.

###### [[25], NTT DOCOMO]

Observation 3:

* *For PRACH preamble detection performances, all candidate SCSs show comparable performances in TDL channels with the same PRACH format. The performance would be improved by increasing the number of PRACH sequence repetitions.*

###### [[26], Qualcomm]

Observation 5: For the PRACH performance of different numerologies in the high frequency regime (Section 2.2.5 in [26]),

* No noticeable difference in the misdetection performance is identified among SCSs.
* With the same CINR, the false alarm rate increases as the SCS or sequence length (i.e., bandwidth) increases.

###### [[56], vivo]

Observation 13: For PRACH channel at low SNR, the preamble sequence correlation shows great effect on the detection performance. The higher SCS, the worse the correlation.

Observation 14: For PRACH channel at high SNR, the bandwidth shows great effect on the detection performance. The larger bandwidth, the better the performance.

Observation 15: For PRACH channel, with the increase of DS, the higher the SCS, the more obvious the performance degradation.

##### Summary of observations for discussion:

8 sources ([61, Ericsson], [68, Huawei], [26, Qualcomm], [56, vivo], [60, ZTE], [64, OPPO], [25, NTT DOCOMO], [12, Intel]) reported evaluation results of PRACH performance in terms of SINR in dB achieving PRACH preamble misdetection probability of 1%. The following are observed.

* For PRACH preamble detection performances for the same PRACH format, all evaluated candidate SCSs (120, 240, 480 and 960 KHz) show comparable performances with the baseline channel models and delay spread values
  + Note: the following is reference when derive the observations.
  + 7 out of 8 sources reported minor performance difference (< or ~ 1 dB) between adjacent SCS for all evaluated candidate SCSs (120, 240, 480 and 960 KHz). The other source ([64, OPPO]) reported minor performance difference among all SCS for TDL-A with 5 and 10ns DS. It reported infinite SINR for 960 KHz SCS and comparable SINR for 120, 240 and 480 KHz SCS in TDL-A with 20ns DS.

Companies are encouraged to provide comments to the above proposal.

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# Remaining issues of evaluation assumptions

### Link level

#### Phase noise model

To compare the impact of different phase noise models, [[14, 61], Ericsson] used the following three sets of phase noise models:

* PN model set 1
  + BS: Ex2 BS
  + UE: Ex2 UE
* PN model set 2
  + BS: Ex2 BS
  + UE: R4-2011494 (ref R4-2011494)
* PN model set 3
  + BS: R4-2010176 DM=0 dB (ref R4-2010176)
  + UE: R4-2010176 DM=5 dB (ref R4-2010176)

###### [[14], Ericsson]

Proposal 9 Capture the following in TR 38.808: Link evaluation based on phase model Ex 2, with characteristics not reflecting realistic devices or current state of the technology, can lead to pessimistic assessment of smaller sub-carrier spacings. It is important for 3GPP to adopt more suitable phase noise models in the discussion and system designs for NR operation in 52.7 – 71 GHz range.

##### Moderator’s comment:

PN model Ex 2 has been agreed in RAN1 to be the baseline for evaluation. Note that other PN models can be optionally used by interested companies for their evaluation. An LS was sent to RAN4 from RAN1 and the investigation of suitable phase noise model is up to RAN4. It seems not in RAN1’s scope to make such statement.

Companies are encouraged to provide comments if any.

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#### Rank 2 transmission

In [[59], Intel], it is argued that use of polarized antennas and high probability of LOS links in short BS to UE distance in indoor deployments creates higher received signal and generates even more opportunities for rank 2 transmission than typically visible in outdoor deployments. So it proposes to add rank 2 transmission as an option in the link level simulation assumptions.

###### [[59], Intel]

Proposal 7:

* Propose to add rank 2 transmission as an option in the link level simulation assumptions.

##### Proposal for discussion:

* Add rank 2 transmission as an option in the link level simulation assumptions.

Companies are encouraged to provide comments to the above proposal.

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### System level

#### Factory scenario A

In [[14], Ericsson], it notes that in TR 38.808 Factory Scenario-A (InF-DL) assumes a BS antenna height of 1.5 meters and that the BS is ceiling mounted. It argues that this is not realistic considering the UE antenna height is also 1.5 meters. It proposes to use the InF-DH scenario instead.

###### [[14], Ericsson]

Proposal 7 In TR 38.808, change the system level evaluation assumption for Factory Scenario A from Dense Clutter & Low BS (InF-DL) to Dense Clutter & High BS (InF-DH) to be consistent with ceiling mounted gNBs.

##### Proposal for discussion:

* Change the system level evaluation assumption for Factory Scenario A from Dense Clutter & Low BS (InF-DL) to Dense Clutter & High BS (InF-DH).

Companies are encouraged to provide comments to the above proposal.

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#### SLS metric

It is proposed in [[59], Intel] to use root mean square effective channel delay spread at the receiver as a metric for system level evaluation of NR in 52.6–71GHz. [[59], Intel] also proposes to use intersymbol interference signal to interference ratio as a metric for system-level evaluation with details given on assumptions of the acceptable intersymbol interference level criteria and of the dynamic FFT window placement for intersymbol interference SIR calculation.

###### [[59], Intel]

Proposal 1:

* Use root mean square effective channel delay spread at the receiver as a metric for system‑level evaluation of NR in 52.6–71GHz

Proposal 2:

* Use intersymbol interference signal to interference ratio as a metric for system-level evaluation of NR in 52.6–71GHz
* Assume the acceptable intersymbol interference level criteria is having 80% of links with intersymbol of 30dB SIR or higher

Proposal 3:

* Assume the dynamic FFT window placement based on the 40% CP length offset from the detected CIR peak for intersymbol interference SIR calculation

##### Moderator’s comment:

Proposal 1 and the 1st bullet of 2 in [59] are related to obtaining delay spread profiles and inter-symbol interference statistics. They are already agreed to be the secondary objective for SLS. Interested companies can for sure use them as the metrics in their evaluation. It seems no need for further discussion and agreement.

The 2nd bullet of proposal 2 and proposal 3 in [59] are detailed assumption in metric calculation which interested companies can use and report. It seems no need for further discussion and agreement as well.

Companies are encouraged to provide comments if any.

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#### Indoor scenario

[[59], Intel] also makes proposals on the description and inclusion of non-ceiling mounted BS for Indoor A Scenario. Another clarification proposal is made in [[59], Intel] regarding the antenna rotation of the BS for the Indoor A and C deployment scenario.

###### [[59], Intel]

Proposal 4:

* Update the indoor A description as follows:
* Office box 120m x 50 m, 12 BS per operator, 2 operator, BS height at 3m (ceiling), UE height 1m, x-axis ISD = 20m and y-axis ISD = 25m, where ISD is define by the distance between two adjacent 10m x 10m virtual box, BS randomly deployed within 10m x 10m virtual box, minimum distance between BS of different operators is 2m.”



Proposal 5:

* Companies are encouraged to provide ceiling mounted BS antenna rotation for indoor A and C deployment scenario.

Proposal 6:

* Proposed to include non-ceiling mounted BS as an option for indoor A scenario, to better reflect non-organized deployments of the multi-operator scenario.

##### Proposal for discussion:

* Update the indoor A description as follows:

Office box 120m x 50 m, 12 BS per operator, 2 operator, BS height at 3m (ceiling), UE height 1m, x-axis ISD = 20m and y-axis ISD = 25m, where ISD is define by the distance between two adjacent 10m x 10m virtual box, BS randomly deployed within 10m x 10m virtual box, minimum distance between BS of different operators is 2m.”



* Add ceiling mounted BS antenna rotation as an option for indoor A and C deployment scenario.
* Add non-ceiling mounted BS as an option for indoor A scenario.

Companies are encouraged to provide comments to the above proposal.

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