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| Technical Report | |
| 3rd Generation Partnership Project;  Technical Specification Group Radio Access Network;  Study on supporting NR from 52.6 GHz to 71 GHz  (Release 17) | |
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| ***3GPP***  Postal address  3GPP support office address  650 Route des Lucioles - Sophia Antipolis  Valbonne - FRANCE  Tel.: +33 4 92 94 42 00 Fax: +33 4 93 65 47 16  Internet  http://www.3gpp.org |
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# Foreword

This Technical Report has been produced by the 3rd Generation Partnership Project (3GPP).

The contents of the present document are subject to continuing work within the TSG and may change following formal TSG approval. Should the TSG modify the contents of the present document, it will be re-released by the TSG with an identifying change of release date and an increase in version number as follows:

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y the second digit is incremented for all changes of substance, i.e. technical enhancements, corrections, updates, etc.

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In the present document, modal verbs have the following meanings:

**shall** indicates a mandatory requirement to do something

**shall not** indicates an interdiction (prohibition) to do something

The constructions "shall" and "shall not" are confined to the context of normative provisions, and do not appear in Technical Reports.

The constructions "must" and "must not" are not used as substitutes for "shall" and "shall not". Their use is avoided insofar as possible, and they are not used in a normative context except in a direct citation from an external, referenced, non-3GPP document, or so as to maintain continuity of style when extending or modifying the provisions of such a referenced document.

**should** indicates a recommendation to do something

**should not** indicates a recommendation not to do something

**may** indicates permission to do something

**need not** indicates permission not to do something

The construction "may not" is ambiguous and is not used in normative elements. The unambiguous constructions "might not" or "shall not" are used instead, depending upon the meaning intended.

**can** indicates that something is possible

**cannot** indicates that something is impossible

The constructions "can" and "cannot" are not substitutes for "may" and "need not".

**will** indicates that something is certain or expected to happen as a result of action taken by an agency the behaviour of which is outside the scope of the present document

**will not** indicates that something is certain or expected not to happen as a result of action taken by an agency the behaviour of which is outside the scope of the present document

**might** indicates a likelihood that something will happen as a result of action taken by some agency the behaviour of which is outside the scope of the present document

**might not** indicates a likelihood that something will not happen as a result of action taken by some agency the behaviour of which is outside the scope of the present document

In addition:

**is** (or any other verb in the indicative mood) indicates a statement of fact

**is not** (or any other negative verb in the indicative mood) indicates a statement of fact

The constructions "is" and "is not" do not indicate requirements.

# Introduction

This clause is optional. If it exists, it shall be the second unnumbered clause.

# 1 Scope

In order to support wide range of services, 5G NR system aims to be flexible enough to meet the connectivity requirements of a range of existing and future (yet unknown) services to be deployable in an efficient manner. NR considers supporting potential use of frequency range up to 100 GHz [1].

NR specifications that have been developed in Rel-15 and Rel-16 define operation for frequencies up to 52.6 GHz, where all physical layer channels, signals, procedures, and protocols are designed to be optimized for uses under 52.6 GHz.

However, frequencies above 52.6 GHz are faced with more difficult challenges, such as higher phase noise, larger propagation loss due to high atmospheric absorption, lower power amplifier efficiency, and strong power spectral density regulatory requirements in unlicensed bands, compared to lower frequency bands. Additionally, the frequency ranges above 52.6 GHz potentially contain larger spectrum allocations and larger bandwidths that are not available for bands lower than 52.6 GHz.

As an initial effort to enable and optimize 3GPP NR system for operation in above 52.6 GHz, 3GPP RAN has studied requirements for NR beyond 52.6GHz up to 114.25GHz including global spectrum availability and regulatory requirements (including channelization and licensing regimes), potential use cases and deployment scenarios, and NR system design requirements and considerations on top of regulatory requirements [2]. The potential use cases identified in the study include high data rate eMBB, mobile data offloading, short range high-data rate D2D communications, broadband distribution networks, integrated access backhaul (IAB), factory automation, industrial IoT (IIoT), wireless display transfer, augmented reality (AR)/virtual reality (VR) wearables, intelligent transport systems (ITS) and V2X, data center inter-rack connectivity, smart grid automation, private networks, and support of high positioning accuracy. The use cases span over several deployment scenarios identified in the study. The deployment scenarios include, but not limited to, indoor hotspot, dense urban, urban micro, urban macro, rural, factor hall, and indoor D2D scenarios. The study also identified several system design requirements around waveform, MIMO operation, device power consumption, channelization, bandwidth, range, availability, connectivity, spectrum regime considerations, and others.

Among the frequencies of interest, frequencies between 52.6 GHz and 71 GHz are especially interesting relatively in the short term because of their proximity to sub-52.6 GHz for which the current NR system is optimized and the imminent commercial opportunities for high data rate communications, e.g., unlicensed spectrum but also licensed spectrum between 57 GHz and 71 GHz. Therefore, it would be beneficial to make a study focused on feasibility of using existing waveforms and required changes for frequencies between 52.6 GHz and 71 GHz, so as to take advantage of imminent commercial opportunities for the specific frequency regime by minimizing the specification burden and maximizing the leverage of FR2 based implementations.

# 2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non‑specific.

- For a specific reference, subsequent revisions do not apply.

- For a non-specific reference, the latest version applies. In the case of a reference to a 3GPP document (including a GSM document), a non-specific reference implicitly refers to the latest version of that document *in the same Release as the present document*.

[1] 3GPP TR 38.913: "Study on Scenarios and Requirements for Next Generation Access Technologies"

[2] 3GPP TR 38.807: "Study on requirements for NR beyond 52.6 GHz".

[3] 3GPP TR 21.905: "Vocabulary for 3GPP Specifications".

[4] ETSI EN 302 567 v2.1.20: "Multiple-Gigabit/s radio equipment operating in the 60 GHz band; Harmonised Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU".

[5] R1-2007549 "Further discussion on B52 numerology" FUTUREWEI.

[6] R1-2007558 "Discussion on physical layer impacts for NR beyond 52.6 GHz" Lenovo, Motorola Mobility.

[7] R1-2007604 "PHY design in 52.6-71 GHz using NR waveform" Huawei, HiSilicon.

[8] R1-2007642 "Physical layer design for NR 52.6-71GHz" Beijing Xiaomi Software Tech.

[9] R1-2007652 "Discussion on required changes to NR using existing DL/UL NR waveform" vivo.

[10] R1-2007785 "Consideration on required changes to NR using existing NR waveform" Fujitsu.

[11] R1-2007790 "Consideration on supporting above 52.6GHz in NR" InterDigital, Inc.

[12] R1-2007847 "System Analysis of NR opration in 52.6 to 71 GHz" CATT.

[13] R1-2007883 "Required changes to NR using existing DL/UL NR waveform" TCL Communication Ltd.

[14] R1-2007926 "Required changes to NR using existing DL/UL NR waveform" Nokia, Nokia Shanghai Bell.

[15] R1-2007929 "On phase noise compensation for NR from 52.6GHz to 71GHz" Mitsubishi Electric RCE.

[16] R1-2009379 "Discussion on Required Changes to NR in 52.6 – 71 GHz" Intel Corporation.

[17] R1-2007965 "On the required changes to NR for above 52.6GHz" ZTE, Sanechips.

[18] R1-2007982 "On NR operations in 52.6 to 71 GHz" Ericsson.

[19] R1-2008045 "Consideration on required physical layer changes to support NR above 52.6 GH" LG Electronics.

[20] R1-2008076 "Discussion on required changes to NR using existing DL/UL NR waveform in 52.6GHz ~ 71GHz" CMCC.

[21] R1-2008082 "Study on the numerology to support 52.6 GHz to 71GHz" NEC.

[22] R1-2008872 "Design aspects for extending NR to up to 71 GHz" Samsung.

[23] R1-2008250 "Discusson on required changes to NR using DL/UL NR waveform" OPPO.

[24] R1-2008353 "Considerations on required changes to NR from 52.6 GHz to 71 GHz" Sony.

[25] R1-2008457 "A Discussion on Physical Layer Design for NR above 52.6GHz" Apple.

[26] R1-2008493 "Discussions on required changes on supporting NR from 52.6GHz to 71 GHz" CAICT.

[27] R1-2008501 "On required changes to NR using existing DL/UL NR waveform for operation in 60GHz band" MediaTek Inc.

[28] R1-2008516 "On NR operation between 52.6 GHz and 71 GHz" Convida Wireless.

[29] R1-2009062 "Evaluation Methodology and Required Changes on NR from 52.6 to 71 GHz" NTT DOCOMO, INC.

[30] R1-2008615 "NR using existing DL-UL NR waveform to support operation between 52p6 GHz and 71 GHz" Qualcomm Incorporated.

[31] R1-2008726 "Discussion on physical layer aspects for NR beyond 52.6GHz" WILUS Inc.

[32] R1-2008769 "Waveform considerations for NR above 52.6 GHz" Charter Communications.

[33] R1-2007550 "On channel access modes in 60GHz" FUTUREWEI.

[34] R1-2007559 "Discussion on channel access for NR beyond 52.6 GHz" Lenovo, Motorola Mobility.

[35] R1-2008976 "Channel access mechanism for 60 GHz unlicensed operation" Huawei, HiSilicon.

[36] R1-2007643 "Channel access mechanism for NR on 52.6-71 GHz" Beijing Xiaomi Software Tech.

[37] R1-2007653 "Discussion on channel access mechanism" vivo.

[38] R1-2007791 "On Channel access mechanisms" InterDigital, Inc.

[39] R1-2007848 "Channel Access Mechanism in support of NR operation in 52.6 to 71 GHz" CATT.

[40] R1-2007884 "Channel access mechanism" TCL Communication Ltd.

[41] R1-2007918 "Channel access mechanisms for NR from 52.6-71GHz" AT&T.

[42] R1-2007927 "Design of NR channel access mechanisms for 60 GHz unlicensed band" Nokia, Nokia Shanghai Bell.

[43] R1-2009380 "Channel Access Procedure for NR in 52.6 - 71 GHz" Intel Corporation.

[44] R1-2007966 "On the channel access mechanism for above 52.6GHz" ZTE, Sanechips.

[45] R1-2007983 "Channel Access Mechanism" Ericsson.

[46] R1-2008046 "Considerations on channel access mechanism to support NR above 52.6 GHz" LG Electronics.

[47] R1-2008091 "Discussion on channel access mechanism for above 52.6GHz" Spreadtrum Communications.

[48] R1-2008157 "Channel access mechanism for 60 GHz unlicensed spectrum" Samsung.

[49] R1-2008251 "Discussion on channel access" OPPO.

[50] R1-2008354 "Channel access mechanism for 60 GHz unlicensed spectrum" Sony.

[51] R1-2008458 "Views on Channel Access Mechanisms for Unlicensed Access above 52.6 GHz" Apple.

[52] R1-2008494 "Discussions on channel access mechanism on supporting NR from 52.6GHz to 71 GHz" CAICT.

[53] R1-2008517 "On Channel Access Mechanism and Interference Handling for Supporting NR from 52.6 GHz to 71 GHz" Convida Wireless.

[54] R1-2008548 "Channel Access Mechanism for NR in 60 GHz unlicensed spectrum" NTT DOCOMO, INC.

[55] R1-2008563 "Discussion on channel access mechanism" ITRI.

[56] R1-2009362 "Channel access mechanism for NR in 52p6 to 71GHz band" Qualcomm Incorporated.

[57] R1-2008717 "Discussion on channel access mechanism for 52.6 to 71GHz unlicensed ban" Potevio

[58] R1-2008770 "Further aspects of channel access mechanisms" Charter Communications.

[59] R1-2007560 "Additional evaluations for NR beyond 52.6GHz" Lenovo, Motorola Mobility.

[60] R1-2007654 "Evaluation on different numerologies for NR using existing DL/UL NR waveform" vivo.

[61] R1-2007792 "Evaluation results for above 52.6 GHz" InterDigital, Inc.

[62] R1-2007928 "Simulation Results for NR from 52.6 GHz to 71 GHz" Nokia, Nokia Shanghai Bell.

[63] R1-2007943 "Considerations on performance evaluation for NR in 52.6-71GHz" Intel Corporation.

[64] R1-2007967 "Simulation results for NR above 52.6GHz" ZTE, Sanechips.

[65] R1-2007984 "Evaluation results for NR in 52.6 - 71 GHz" Ericsson.

[66] R1-2008047 "Considerations on phase noise compensation to support NR above 52.6 GHz" LG Electronics.

[67] R1-2008873 "Evaluation results for extending NR to up to 71 GHz" Samsung.

[68] R1-2009615 "Discussion on other aspects" OPPO.

[69] R1-2008459 "Evaluation results for Physical Layer Design for NR above 52.6GHz" Apple.

[70] R1-2009062 "Potential Enhancements for NR on 52.6 to 71 GHz" NTT DOCOMO, INC.

[71] R1-2008771 "Performance evaluations for NR above 52.6 GHz" Charter Communications.

[72] R1-2009610 "Link level and System level evaluation for NR system operating in 52.6GHz to 71GHz" Huawei, HiSilicon.

# 3 Definitions of terms, symbols and abbreviations

## 3.1 Terms

For the purposes of the present document, the terms given in 3GPP TR 21.905 [3] and the following apply. A term defined in the present document takes precedence over the definition of the same term, if any, in 3GPP TR 21.905 [3].

## 3.2 Symbols

For the purposes of the present document, the following symbols apply:

B transmission bandwidth

G antenna gain

## 3.3 Abbreviations

For the purposes of the present document, the abbreviations given in 3GPP TR 21.905 [3] and the following apply. An abbreviation defined in the present document takes precedence over the definition of the same abbreviation, if any, in 3GPP TR 21.905 [3].

BS Base Station

BWP Bandwidth Part

ED Energy Detect

EDT Energy Detect Threshold

EIRP Equivalent Isotropic Radiated Power

FDD Frequency Duplex Division

IAB Integrated Access Backhaul

ISM Industrial, Scientific and Medical

ITU International Telecommunication Union

LBT Listen Before Talk

MCOT Maximum Channel Occupancy Time

NR New Radio

OCB Occupied Bandwidth

OOBE Out-Of-Band Emission

PSD Power Spectral Density

PTP Point to point

SCS Subcarrier Spacing

SI Study Item

SID Study Item Description

TDD Time Duplex Division

UE User Equipment

V2X Vehicle to Everything

WAN Wide Area Network

# 4 Study of required changes to NR

## 4.1 RAN1 Aspects

### 4.1.1 General description of study in RAN1

For supporting NR operation in both licensed and unlicensed band in the frequency range from 52.6 GHz to 71 GHz, FR2 numerologies and additional numerologies beyond that supported currently in NR are studied. Existing framework for numerology scaling is considered i.e. 2μ ×15 subcarrier spacing to select the candidates. For SSB transmissions, it is investigated whether or not µ > 4 (larger than 240 kHz) is needed and corresponding impacts, if any, on the aspects including at least SSB pattern, multiplexing of other signal/channels, and transmission window, if supported. For data and control channel transmissions, it is investigated if µ > 3 (larger than 120 kHz) is needed and corresponding impacts, if any, on aspects including at least processing timelines, PDCCH monitoring capability (BD/CCE), scheduling enhancements, beam-management, and reference signal design. For investigating the need for higher numerologies, some of the key aspects that are studied are the impact due to phase noise, delay spread, TAE, analog beam switching delay, and impact to coverage, spectral efficiency and peak data rates, and relative delay in intra-cell/inter-cell multi-TRP operations.

### 4.1.2 Candidate numerology and bandwidth

It was observed that amount of specification effort increases with the number of new numerologies enabled and supported for 52.6 GHz to 71 GHz frequency.

In order to minimize specification effort while maximizing supported use cases and deployment scenarios applicable for 52.6 GHz to 71 GHz frequency, It is recommended to support 120 kHz subcarrier spacing with normal CP length, and at least one more subcarrier spacing. It is recommended to consider supporting at most up to three subcarrier spacings, including 120 kHz subcarrier spacing. Applicability of the supported subcarrier spacing to particular signals and channels should be further discussed in the corresponding WI phase.

It is recommended that numerologies 240 kHz, 480 kHz, and 960 kHz are considered as candidates for additional numerologies in addition to 120 kHz, and numerologies outside this range are not supported for any signals or channels.

In order to bound implementation complexity, it is recommended to limit the maximum FFT size required to operate system in 52.6 GHz to 71 GHz frequency to 4096 and to limit the maximum of RBs per carrier to 275 RBs.

Selection of the additional subcarrier spacing (on top of 120 kHz) should consider versatility of being able to support various applications and deployment scenarios with all the subcarrier spacings that would be supported by specification, accounting for what is already supported in Rel-15 and Rel-16 specifications.

Some companies have noted that ability for a deployed system to operate with a single numerology for all channels and signals is beneficial, and some companies have further noted benefit remains even if SSB numerology is different. Some companies have noted mixed numerology operation is functional and is supported in Rel-15 and Rel-16 specifications (e.g. 240 kHz SSB subcarrier spacing with 120 kHz subcarrier spacing for PDCCH/PDSCH/PUSCH/PUCCH/PRACH in an initial BWP and activation of a dedicated BWP with SCS different than the initial BWP) and consideration of single numerology operation is not needed.

Overall implementation complexity for supporting a specific subcarrier spacing may need to consider the following, but not limited to:

- processing complexity for equalization including inter-carrier interference mitigation (if required to support higher modulation orders) and compensation, and FFT complexity per unit time for a given bandwidth,

- complexity associated with supporting multiple component carriers to reach a specific throughput,

- complexity associated with supporting given reduced (in absolute time) requirements on UE processing times (e.g. N1, N2, N3, Z1, Z2, Z3, etc) and UE PDCCH processing budget as a function of subcarrier spacing, if scheduling and monitoring unit is maintained to be one slot,

- supported features indicated by UE capability signalling or implemented by the gNB,

- complexity associated with supporting required timing error tolerance which may need to consider initial timing error, timing advance setting, TA granularity, MIMO TAE (TAE value will be defined by RAN4), multi-TRP timing alignment as a function of SCS, whether mixture or a single subcarrier spacing for signals is configured, and deployment scenarios,

- complexity associated with supporting higher sampling rates and with channel bandwidth larger than 2 GHz.

It is observed that for a single carrier with the same number of transmitted symbols, in general, smaller subcarrier spacing may potentially provide larger coverage due to use of smaller bandwidth and gears towards (but not limited to) coverage driven scenarios.

It is observed that for a single carrier, in general, larger subcarrier spacing may potentially provide higher peak data rates due to use of larger bandwidth and gears towards (but not limited to) peak data-rate driven scenarios.

### 4.1.3 Investigation of physical layer impact from candidate numerology and bandwidths

It is recommended to strive for maximum commonality for the system design for licensed and unlicensed operation for NR from 52.6GHz to 71GHz, and maximize re-use of the existing NR design.

## 4.2 RAN4 aspects

*Editor’s Note: This section will be further categorized into sub-sections depending on discussions*

# 5 Study of channel access mechanism for 60 GHz

## 5.1 Identification of regulatory aspects for consideration

Use the CCA check procedure in EN 302 567 (per RAN1 understanding as from RAN1 #102-e) as the baseline for channel access for 60GHz band when LBT is applied. The following can be discussed further during normative work:

- whether CAPC and contention window adjustment mechanisms are introduced,

- whether ED threshold change is needed, e.g., due to changes in bandwidth, beamforming gain etc, and

- whether contention window range needs to be adjusted.

The OCB requirement of draft version v2.1.20 of EN 302 567 [4] implies that

- device supports one or multiple declared nominal channel bandwidths,

- for each declared nominal channel bandwidth, RAN1 design should support at least one physical layer signal/channel transmission that occupies at least 70% of the nominal channel bandwidth.

Mapping of nominal channel bandwidth to bandwidth definitions in NR should be further studies when specifications are developed.

The RAN1 understanding of the CCA check procedure in draft v2.1.20 of EN 302 567 is as follows:

- when performing CCA before initiating transmission, during count down, when an observation slot fails ED, the counter freezes, and will continue count down 8us after the interference is detected to be gone.

## 5.2 Channel access and interference mitigation techniques

For NR operating with LBT, maximum channel occupancy time (MCOT) duration is 5 msec, including all gaps inside the COT. Discussions related to further reductions in MCOT due to potential definition of CAPC will be handled separately

On the LBT bandwidth (bandwidth over which a single contiguous LBT is performed) relative to channel bandwidth (as defined in RAN4), the following alternatives have been discussed. Further down-selection of one or more of these alternatives (if needed) should be further discussed when specifications are developed.

- Alt 1: LBT bandwidth equals channel bandwidth

- Alt 2: LBT bandwidth equals the minimum of channel bandwidth and the transmission bandwidth (number of RBs for a given transmission)

- Alt 3: LBT bandwidth can be wider than channel bandwidth

- Alt 4: LBT bandwidth can be narrower than the channel bandwidth, with multiple LBT subband within a channel

- Alt 5: LBT bandwidth equals with minimum supported channel bandwidth or multiples of the minimum supported channel bandwidth

For operation where LBT is not required, it can be further discussed when specifications are developed.

- Whether to introduce additional conditions/mechanisms for no-LBT to be used, or leave it for gNB implementation.

- When no-LBT mode is used, whether to introduce additional restrictions, such as DFS needs to be applied, ATPC needs to be applied, long term sensing needs to be applied, certain duty cycle limitation, certain transmit power limitation, MCOT limits, etc, or leave the restriction for gNB implementation.

- When no-LBT mode is used, whether to introduce mechanism for the system to fallback to LBT mode, or leave it for gNB implementation.

# 6 Summary of evaluation study

## 6.1 Summary of link level evaluations

7 sources, [65], [30], [60], [68], [25], [29], and [16], 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, [65], [30], [60], and [25], reported PBCH performance in terms of SINR in dB achieving PBCH BLER target of 10%. 2 sources, [9], and [65], compared link budget of SSB for difference SCS.

- For PSS and SSS detection performance, all evaluated candidate SCSs (120, 240, 480 and 960 kHz) show comparable performances with the channel models and delay spread values parameters provided in Table A.1-1. The following were observed from the evaluations:

- The performance degrades as the increase of SCS

- 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 [25] reported more than 3 dB performance gap of 960 kHz SCS compared to other 120, 240 and 480 kHz 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 channel models and delay spread parameters provided in Table A.1-1.

- 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.

- In terms of SSB link budget, smaller SCS have better coverage than larger SCS.

- The MCL and MIL difference between 120 kHz SCS and 480 kHz SCS is about 5 dB. The MCL and MIL difference between 120 kHz SCS and 960 kHz SCS is about 8 dB.

8 sources, [65], [72], [30], [60], [64], [68], [29], and [16], reported evaluation results of PRACH preamble detection performance in terms of SINR in dB achieving PRACH preamble misdetection probability of 1% with evaluation assumptions and parameters as in Table A.1-1. Two sources, [65], and [20], compared link budget of PRACH for different SCS. 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.

- 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 [68] reported minor performances difference among all SCS for TDL-A with 5 and 10ns delay spread. It reported infinite SINR for 960 kHz SCS and comparable SINR for 120, 240 and 480 kHz SCS in TDL-A with 20ns delay spread using the metrics of preamble miss detection probability of 1% and the estimated timing error is within [-Tcp/2, Tcp/2].

- For PRACH link budget of the same PRACH format and the same sequence length, maximum isotropic loss (MIL) and maximum coupling loss (MCL) degrade as the subcarrier spacing is increased, negatively impacting coverage.

- Two sources, [65], and [23], reported that with UE power limitation of 25 dBm EIRP, the MCL/MIL difference between 120 kHz SCS and 480 kHz SCS is about 4 to 5 dB; the MCL/MIL difference between 120 kHz SCS and 960 kHz SCS is about 8 dB.

- One source [65] reported that without UE power limitation of 25 dBm EIRP (but still under regulatory limits), the MCL difference between 120 kHz SCS and 480 kHz SCS is less than 2.5 dB; the MCL difference between 120 kHz SCS and 960 kHz SCS is less than 1 dB.

- One source [65] reported that without UE power limitation of 25 dBm EIRPs (but still under regulatory limits), compared to short PRACH sequence length, longer PRACH sequence length improve MCL/MIL significantly for 120 kHz SCS due to wider bandwidth for a given SCS.

For CP-OFDM, the following are observed regarding the impact of DMRS to BLER performance.

- One source [61] reported performance improvement with increased number of DMRS symbols or increased DMRS density especially for higher modulation order for 960 kHz SCS in TDL-A (5 ns and 10 ns delay spread).

- One source [18] reported for 480 kHz SCS and below with large delay spread (TDL-A with 40 ns delay spread), the room for performance improvement with a change to the Rel-15 DMRS design is very limited.

- One source [16] reported a performance drop when frequency domain OCC is enabled especially for higher order modulation such as 64 QAM (MCS 22) for 960 kHz SCS in TDL-A (10ns and 20 ns delay spread) and 480 kHz SCS (20 ns delay spread). The performance gap increases when channel delay spread increases.

- One source [30] reported performance improvement with a new DMRS pattern featured by high frequency density (i.e., every RE) and 2-FD-OCC across adjacent REs for 960 kHz SCS in TDL-A (20 ns and 40 ns delay spread).

- One source [14] reported that with Rel-15 DMRS type-1, different delay spread values (10ns and 20ns) have a negligible impact to the demodulation performance of PDSCH for a high SCS (such as 960 kHz).

7 sources, [65], [72], [30], [60], [68], [14], and [25], evaluated DFT-S-OFDM PUSCH BLER performance with different SCS.

- Compared to CP-OFDM when CPE-only compensation is enabled, DFT-s-OFDM is more robust under phase noise.

- For low and medium MCSs (QPSK and 16QAM), there’s minor performance difference among evaluated SCSs up to 960 kHz.

- With normal CP, for high MCS (64QAM), the performance improves as the increase of SCS, 120 kHz SCS shows up to ~2.0dB loss compared to other larger SCS.

- One source [65] reported a performance gap of 1.4 ~ 1.8 dB between 120 and 960 kHz SCS.

- One source [72] reported a performance gap of 1.3 ~ 2.5 dB between 120 and 960 kHz SCS.

- One source [30] reported a performance gap of 1.2 ~ 1.7 dB between 120 and 960 kHz SCS.

- One source [60] reported a performance gap of ~ 1.4 dB between 120 and 960 kHz SCS.

- One source [14] did not report numerical SINR results in table but provided figures showing approximately similar performance difference, ~ 2 dB, between 120 and 960 kHz SCS.

- One source [25] reported a performance gap of more than 7 dB performance gap between 120 kHz SCS and other SCS (240, 480 and 960 kHz) at TDL-A 5 ns DS. It also reported 120 kHz SCS cannot meet the BLER target of 10% at TDL-A 10ns DS and 960 kHz SCS cannot meet the BLER target of 10% at TDL-A 20ns DS.

- Another source [68] reported 120 and 240 kHz SCS 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%.

- One source [30] reported an error floor for 960 kHz SCS for BLER target 1%.

- One source [60] reported an error floor for 960 kHz SCS for BLER target 10%.

- One source [68] 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%.

For CP-OFDM, with evaluation assumptions and parameters as in Table A.1-1, the following are observed when CPE-only compensation based on the existing Rel-15 NR PTRS structure is used for normal CP when delay spread is not large. The performance is measured in terms of SINR in dB achieving BLER target of 10% or 1%.

- For low MCS (QPSK) and medium MCS (16QAM), there is minor performance difference between different SCS values up to 960 kHz.

- For high MCS (64QAM), the performance improves in general as the increase of SCS.

- For high MCS (64QAM), 13 sources, [65], [72], [30], [60], [64], [68], [14], [6], [59], [25], [22], [29], [16], and [11], compared performance of 120 and 240 kHz SCS in 400 MHz bandwidth.

- For 10% BLER target, there is a performance gap between 120kHz and 240kHz SCS, where 240 kHz SCS performs better.

- One source [65] reported better performance of 240 kHz SCS in CDL-D. It also reported both SCS cannot meet 10% BLER target for the other evaluated channel model.

- 3 sources, [72], [68], and [14], reported both SCS cannot meet 10% BLER target.

- 4 sources, [60], [64], [25], and [11], reported 120 kHz SCS cannot meet 10% BLER target, while 240 kHz SCS can.

- One source, [6] and additional results in [59], reported better performance of 240 kHz SCS at TDL-A 5 and 10ns. It also reported that both SCS cannot meet 10% BLER target for other evaluated cases.

- One source [16] reported better performance of 240 kHz SCS in CDL-D. It also reported that both SCS cannot meet 10% BLER target for other evaluated cases.

- 2 sources, [30], and [22], reported better performance of 240 kHz SCS.

- One source [29], reported comparable performance for both SCS in CDL-D. It also reported better performance of 120 kHz SCS for the other evaluated channel models.

- For high MCS (64QAM), 13 sources, [65], [30], [60], [64], [68], [14], [6], [59], [25], [22], [29], [16], [71], and [11], compared performance of 240 and 480 kHz SCS in 400 MHz bandwidth.

- For 10% BLER target, there is a performance gap between 240kHz and 480kHz SCS where 480 kHz SCS performs better.

- One source [65] reported better performance for 480 kHz SCS in CDL-D. It also reported 240 kHz SCS cannot meet 10% BLER target for the other evaluated channel model.

- 3 sources, [68], [14], and [71], reported 240 kHz SCS cannot meet 10% BLER target, while 480 kHz SCS can.

- One source [6] and additional results in [59], reported better performance of 480 kHz SCS at TDL-A 5 and 10ns. It also reported 240 kHz SCS cannot meet 10% BLER target for other evaluated cases.

- One source [16] reported better performance of 480 kHz SCS in CDL-D. It also reported 240 kHz SCS cannot meet 10% BLER target for other evaluated cases.

- 6 sources, [30], [60], [64], [25], [22], and [11], reported better performance of 480 kHz SCS.

- One source [29], reported comparable performance for both SCS in CDL-D. It also reported better performance of 240 kHz SCS for the other evaluated channel models.

- For high MCS (64QAM), 14 sources, [65], ,[72], [30], [60], [64], [68], [14], [6], [59], [25], [22], [29], [16], [71], and [11], compared performance of 480 and 960 kHz SCS in 400 MHz bandwidth.

- For 10% BLER target, there is a performance gap between 480kHz and 960kHz SCS where 960 kHz SCS performs better.

- 7 sources, [65], [64], [68], [14], [6], [59], [71], and [11], reported a greater than 1 dB gain of 960 kHz SCS.

- 3 sources, [30], [60], and [22], reported a smaller than 1 dB performance gain of 960 kHz SCS.

- One source [72] reported better performance of 480 kHz SCS for CDL-B 50ns and better performance of 960 kHz SCS for other evaluated cases. In all comparison, the difference is greater than 1 dB.

- Two sources, [25], and [16], reported a better performance of 480 kHz SCS than 960 kHz SCS at 20ns DS in TDL-A where 960 kHz SCS cannot meet 10% BLER target and comparable performance for both SCS in all other evaluated cases.

- One source [29] reported comparable performance for both SCS in CDL-D. It also reported better performance of 480 kHz SCS in TDL-A 5ns and better performance of 960 kHz SCS in CDL-B 20ns.

- For 1% BLER target, the performance for 960kHz SCS is better than 480kHz SCS.

- Among sources reported SINR values when both SCS can meet 1% BLER target, the absolute value of the performance gap between 480 kHz and 960 kHz SCS is larger than that for 10% BLER target.

- For high MCS (64QAM), 4 sources, [65], [60], [14], and [22], compared performance of 480 and 960 kHz SCS in 1600 or 2000 MHz bandwidth. 4 out of 4 sources reported performance gain around 4 ~ 5 dB of 960 kHz SCS for 10% BLER target. All 4 sources also reported that 480 kHz SCS cannot meet 1% BLER target.

For CP-OFDM, with evaluation assumptions and parameters as in Table A.1-1 (including optional delay spread value), the following are observed when CPE-only compensation based on the existing Rel-15 NR PTRS structure is used with respect to CP type and large delay spread.

- 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 when compared on the basis of equal MCS (code rate). If comparing on the basis of equal TBS (equal throughput), the performance of ECP is degraded due to higher overhead of ECP.

- Among 11 sources, [65], [72], [30], [60], [64], [68], [6], [59], [5], [29], [16], and [11], evaluated with large delay spread (i.e. 40 ns in TDL-A and/or 50ns in CDL) based on the existing Rel-15 NR PTRS structure for normal CP, 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 10% BLER target.

- The other source [5] evaluated SCS 960 kHz with CPE compensation at MCS16 with normal CP in TDL-A channel with 40ns DS. It reported that the BLER for SCS 960 kHz, MCS16, and Normal CP is not acceptable (cannot meet 10% BLER target) for 40ns DS.

- 10 sources, [65], [72], [30], [60], [64], [68], [6], [59], [29], [16], and [11], 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 PTRS structure with normal CP. Among 10 sources, 5 sources, [18], [72], [9], [60], [6], [59], and [29], also evaluated extended CP at least for 960 kHz SCS with CPE compensation based on the existing Rel-15 NR PTRS 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 PTRS structure is used. The other source [29] reported better performance of smaller SCS.

- 5 out 5 sources observed the performance of 960 kHz SCS with extended CP is significantly improved compared to with normal CP for large delay spread case when compared on the basis of equal MCS (code rate).

- 4 sources, [18], [72], [9], [6], and [59], compared throughput of normal CP and extended CP at least for 960 kHz SCS with CPE compensation based on the existing Rel-15 NR PTRS structure. They all reported worse throughput of extended CP.

For CP-OFDM, the following are observed with respect to phase noise compensation and PTRS.

- Compared to no phase noise compensation, CPE 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.

- Two sources, [61], and [15], reported that increased PTRS density in frequency domain based on Rel-15 configuration does not provide significant performance benefits.

- For a given SCS, the complexity of ICI compensation increases as the number of ICI filter tap increases

- For MCS 22 evaluation of the same SCS, performance gain of ICI compensation with additional complexity of multi-tap filtering compared to CPE-only compensation is observed when there is sufficient number of PTRS in the frequency domain for 120, 240 and 480 kHz SCS.

- One source [65] showed performance gain of ICI compensation compared to CPE-only compensation for all evaluated SCS

- One source [72] evaluated ICI compensation and compared with CPE-only compensation. It reported performance gain for all evaluated SCS.

- One source [30] compared the performance of CPE and ICI compensation for 120 kHz SCS reported performance gain of ICI compensation.

- One source [68] compared the performance of CPE and ICI compensation for all SCS. It reported performance gain of ICI compensation for 240 kHz and 480 kHz SCS. It reported performance gain of ICI compensation in CDL-B but a performance loss in TDL-A for 960 kHz SCS. It also reported that 120 kHz SCS still cannot meet 10% BLER target with ICI compensation.

- One source [14] reported performance gain of ICI compensation for 120, 240 and 480 kHz SCS. It also reported performance gain of ICI compensation for 960 kHz SCS at 2GHz bandwidth and a performance loss of ICI compensation for 960 kHz SCS at 400MHz bandwidth.

- One source [69] evaluated ICI compensation for different SCS with a new PTRS pattern. It reported improvement of ICI compensation compared to CPE-only compensation.

- One source [22] evaluated 120 kHz and 240 kHz SCS performance with ICI compensation based on some new PTRS pattern and reported performance improvement.

- One source [5] compared ICI performance among SCS. It reported performance gain of multi-tap ICI filter over CPE compensation for 120, 240 and 480 kHz SCS.

- One source [16] 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.

- For MCS 22 with normal CP when delay spread is not large, it is observed that ICI compensation of multi-tap filtering is required for 120, 240 and/or 480 kHz SCS to achieve comparable performance (< 1 dB difference) to that of 960 kHz SCS with CPE-only compensation for 10% BLER target

- 2 sources, [65], and [14], reported comparable performance of 480 kHz SCS with ICI compensation and 960 kHz SCS with CPE compensation in 1600 MHz bandwidth

- 2 sources, [68], and [14], reported comparable performance of 480 kHz SCS with ICI compensation and 960 kHz SCS with CPE compensation in 400 MHz bandwidth

- One source [72] reported comparable performance of 240 kHz SCS with ICI compensation and 960 kHz SCS with CPE compensation in 400 MHz bandwidth

- One source [30] evaluated and compared 120 kHz SCS with ICI compensation to larger SCS with CPE compensation. It reported that at MCSs 22 and 24, 120 kHz SCS with ICI compensation performs almost equal to 960 kHz SCS with CPE-only compensation in 400 MHz bandwidth.

- One source [5] reported comparable performance of 480 kHz SCS with ICI compensation and 960 kHz SCS with CPE compensation in TDL-A 5 and 10ns as well as in CDL-D 30ns in 400 MHz bandwidth.

- At very high MCS (e.g., MCS 26 or MCS 28), three sources, [16], [30], and [73], compared ICI and CPE compensation using the Rel-15 PTRS.

- One source [16] evaluated the phase noise compensation performance with MCS 28 when delay spread is not large. It is observed that de-ICI technique with 3-taps filter for smaller subcarrier spacing (240 kHz) fails even though there are sufficient number of PTRS tones available for ICI covariance construction.

- One source [30], compared the performance of CPE and ICI compensation and reported for MCS 26, 120kHz SCS with ICI compensation suffers from residual ICI and is outperformed by 960kHz SCS with CPE-only compensation when delay spread is not large.

- One source [72] showed that for MCS 28, de-ICI technique with large number of taps (11, 9 and 7 taps for 120, 240 and 480 kHz SCS respectively) outperforms 960 kHz with CPE compensation only when delay spread is not large. For normal CP, it also reported that 960 kHz with 3-tap ICI compensation has comparable performance to other SCS with larger number of taps (11, 9 and 7 taps for 120, 240 and 480 kHz SCS respectively) for MCS 28 when delay spread is not large. It also reported that with large delay spread (50ns in CDL), ECP and ICI compensation with at least 3 taps filter are needed for 960 kHz SCS to reach 1% BLER target for MCS 26.

- For high MCS (64QAM) with normal CP when delay spread is large (TDL-A with 40 ns and/or CDL-B with 50ns), 4 sources compared performance of smaller SCS (120, 240 and/or 480 kHz) with ICI compensation to that of 960 kHz SCS with CPE compensation and reported worse performance of 960 kHz SCS with CPE compensation for 10% BLER target.

- One source [65] reported a performance gain of 5 dB in TDL-A 40ns and 0.3 dB in CDL-B 50ns for 480 kHz SCS with ICI compensation compared to 960 kHz SCS with CPE compensation in 1600 MHz bandwidth.

- One source [72] reported a performance gain of 2.6 dB (for 240 kHz SCS) and 1.6 dB (for 120 kHz SCS) in CDL-B 50ns with ICI compensation compared to 960 kHz SCS with CPE compensation.

- One source [68] reported a performance gain of 1 dB in CDL-B 50ns for 480 kHz SCS with ICI compensation compared to 960 kHz SCS with CPE compensation. It also reported the performance of 120 kHz with ICI compensation cannot meet the 10% BLER target.

- One source [5] reported the performance of 960 kHz SCS with CPE compensation cannot meet the 10% BLER target. It also reported that the performance of 480 kHz SCS with ICI compensation cannot meet the 10% BLER target in TDL-A 40ns. With ICI compensation, it also reported comparable performance of 120, 240 and 480 kHz SCS in CDL-B 50ns and comparable performance of 120 and 240 kHz SCS in TDL-A 40ns.

- Multiple sources evaluated and compared ICI compensation schemes using the existing Rel-15 NR distributed PTRS structure and/or new PTRS patterns. The results from different sources are not aligned on whether new PTRS patterns perform better than existing Rel-15 PTRS structure when ICI compensation is used.

- One source [15] evaluated with 120 and 240 kHz SCS and reported that the PN compensation with block-based PTRS and cyclic sequence significantly outperforms in spectral efficiency both CPE compensation and de-ICI Wiener filtering with distributed PTRS, even when the density of the scattered pattern is increased above the Rel.15 defined density.

- One source [18] reported that 3-tap direct de-ICI compensation with Rel-15 PTRS outperforms ICI filter approximation approach with clustered PTRS. 3-tap direct de-ICI compensation with a clustered PTRS structure does not offer any performance advantage over the existing Rel-15 NR distributed PTRS structure.

- One source [27] reported that with a 3-tap BLS ICI equalizer, a clustered PTRS structure does not offer any performance advantage over the existing Rel-15 NR distributed PTRS structure.

- One source [66] reported that the performance of clustered PTRS allocation is worse than that of Rel-15 PTRS 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 PTRS based ICI compensation scheme.

- Two sources, [22], and [69], evaluated the performance with some new PTRS patterns (e.g. chunk based PTRS pattern to allow adjacent PTRS symbols in frequency) and reported that the performance with ICI compensation based on new PTRS patterns is better than the Rel-15 pattern with CPE compensation only.

- One source [30] 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). It also observed that 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) and with a fixed effective code rate, the performance slightly improves as the PTRS overhead increases.

- For high MCS (64QAM) with normal CP, 2 sources, [65], and [14], compared performance of 480 and 960 kHz SCS in 1600 MHz bandwidth when ICI compensation is used based on Rel-15 PTRS.

- When delay spread is not large, both sources reported a smaller than 1 dB performance gain of 960 kHz SCS for both 10% and 1% BLER target in TDL-A. One source, [65], reported that for CDL-B, there is up to 1.1 dB gain at 1% BLER target for 960 kHz SCS.

- When delay spread is large (TDL-A with 40 ns DS), one source, [65], reported 480 kHz SCS performed 3.6 dB better than 960 kHz SCS at 10% BLER target and 960 kHz SCS cannot meet the 1% BLER target.

For CP-OFDM, two sources, [65], and [72], evaluated PDSCH BLER performance with optional PN models in addition to PN model in Table A.1-1. Note that such optional PN models are not confirmed and/or recommended by RAN4 at the time of RAN1#103-e.

- When CPE-only compensation is used with an optional PN model at the UE or at BS and UE, it is observed by both sources that there is significantly less dependence of BLER performance on SCS compared to the PN model in Table A.1-1. For all test cases, no error floor is observed for smaller SCS with TDL-A or CDL-B/CDL-D for 1% BLER target. There is around 1 to 2 dB performance difference between consecutive SCSs for 1% BLER target.

- However, multiple sources expressed concerns on the validity of such optional PN models given no confirmation and/or recommendation from RAN4. In consequence, there’s a concern on whether and how the observations based on such optional PN models can be used given no RAN4 input on these optional PN models.

## 6.2 Summary of system level evaluations

For comparison of No-LBT (NLBT) and Tx side ED based omnidirectional sensing (TxED-Omni) for Indoor scenario A, 6 companies have compared No-LBT with Tx Side ED based Omni sensing TxED-Omni LBT and provide the following observations:

- Source [37], show tail and median benefits of using TxED-Omni LBT on DL, at high loading. In other cases, including all loads for UL and other loads for DL, TxED-Omni LBT scheme shows losses. All results are at ED threshold -47 dBm.

- Source [16] shows gains for 5%ile DL throughput at high loads with TxED-Omni LBT. In other cases, including all loads for UL and other loads for DL, TxED-Omni LBT scheme shows losses. All results are at ED threshold -47 dBm.

- Source [65], [35], [42], [56] and [67] show loss for TxED-Omni LBT with an EDT of -47 dBm or -48 dBm for all cases.

For comparison of No-LBT with directional LBT (TxED-Dir) for Indoor Scenario A, 6 sources, [37], [72], [62], [67], [43], and [65], provided results and the following are observations from the evaluations:

- Results from source [37] show gain for directional LBT (TxED-Dir with EDT -47 dBm) over No-LBT for DL, high load, for tail, median and upper tail users, and for UL, high load for tail users. For all other cases in this comparison, TxED-Dir underperforms No-LBT.

- Results from source [62], provided evaluations for 100% DL presented low, medium and high load results. For all loads, their results show significant loss for both directional and omni-directional LBT for median and high-end users. Only the tail users may have some benefit from directional LBT (as compared to No-LBT), while omni-LBT provides loss also in this case (EDT -48 dBm).

- Results from source [65] show No-LBT outperforms directional LBT with EDT -47 dBm and directional LBT with ED -32 dBm for gNB, ED -41 dBm for UE.

- Results from [67] show gain in medium and high loads for directional LBT over No-LBT at EDT -47 dBm for all users for DL as well as for UL. At low loads TxED-Dir underperforms No-LBT.

- Results from source [43] shows gains for DL throughput at high loads with TxED-Dir LBT for all antenna configurations when BSs are ceiling mounted, and gains for 5%ile DL throughput at high loads when the BS are not ceiling mounted. In other cases, including all loads for UL, TxED-Dir LBT scheme shows losses. All results are at ED threshold of -48 dBm.

- Results from source [72] largely shows loss for directional LBT over No-LBT for all loading levels and users, except DL, tail users at high loading where the results are comparable. Results were based on TxED-Dir with CW-Max of 127 with EDT of -47 dBm.

For comparison of Omni LBT (TxED-Omni) with directional LBT (TxED-Dir) for Indoor Scenario A, 8 sources, [37], [64], [62], [67], [43], [56], [65], and [72], provided results and the following are observations from the evaluations:

- For Omni LBT (TxED-Omni) with directional LBT (TxED-Dir) have been done with using the same ED Threshold. Additionally, source [65] evaluated directional LBT with adjusted thresholds ED -32 dBm for gNB, and ED -41 dBm for UE. Multiple companies have evaluated adjustments to ED Threshold with directional sensing either implicitly or explicitly.

- Results from source [37] show that omni-directional is better than directional LBT in tail and median performance, and marginal difference in other cases. Both omni-directional and directional LBT use the same ED threshold of -47 dBm.

- Results from source [67] shows gain at all loading levels for directional LBT over omni-LBT (-47 dBm) for all users, for DL and UL traffic.

- Results from source [43] shows that for UL TxED-Dir LBT provides better performance relative to TxED-Omni for low ED thresholds (i.e., -55 and -65 dBm) but losses for high thresholds (i.e., -48 dBm). As for DL, TxED-Dir LBT provides consistently better performances than TxED-Omni. The gain of directionality increases with more directional UE beams.

- Results from source [56] show largely a comparable performance for omni and directional sensing using equal threshold, with small benefit of directionality under gNBs with narrower beams.

- Results from source [65] show that directional LBT with adjusted thresholds (ED -32 dBm for gNB, ED -41 dBm for UE) and directional LBT with ED -47 dBm, and omni-directional LBT with ED -47 dBm have comparable performance.

- For 100% DL traffic, results from source [62] show that directional LBT TxED-Dir outperforms TxED-Omni at low as well as medium loads – for median, tail as well as upper tail users. The results use EDT -48 dBm.

- For 100% DL traffic, results from source [64] shows gains in directional LBT for tail users and median users at ED thresholds -68 dBm and -62 dBm. The gains are also present in DL+UL Traffic at ED threshold -68 dBm and -62 dBm.

- For coexistence, results from source [64] shows that an operator using directional LBT benefits in the presence of an operator using Omni LBT, relative to a deployment where both operators use Omni-LBT. The results used ED threshold of -68 dBm.

- Results from source [72] show that directional LBT (TxED-Dir) does not outperform Omni LBT (TxED-Omni).

For comparison of No-LBT with receiver assisted LBT for Indoor Scenario A, 3 sources, [65], [72], and [37], provided results and the following are observations from the evaluations:

- Description of the different versions of receiver assistance modelled are provided section X.X.X.

- Results from source [65] uses omni-sensing at receiver. The results do not show benefit for receiver assistance over No-LBT.

- Results from source [37] use an EDT -47 dBm and in the results, RxA-4-Omni gains in both DL and UL relative to No-LBT for tail users at high loads. RxA-4-Omni gains in DL but loses in UL relative to No-LBT for medium and high loads at all other user percentiles and mean.

- Results from source [72], the receiver-only LBT (RxA-3) shows tail UPT and mean UPT gain compared to No-LBT in low, medium, and high traffic loads with InH Open Office channel model and InH mixed channel model in both UL and DL.

- In comparison with No-LBT, results from source [72] shows Receiver-assisted LBT (RxA-2) tail UPT gain in DL with high traffic load for InH open office channel model and loss in other cases. Also, the results show Receiver-assisted LBT Tail UPT gain in DL with low, moderate and high traffic load for InH mixed channel model and loss in other cases.

For comparison of receiver assisted LBT versions with Omni LBT (Tx-ED-omni), and directional LBT (TxED-dir) for Indoor Scenario A, 4 sources, [72], [56], [37], and [65], provided results and the following are observations from the evaluations:

- Results from [65] show similar performance of receiver assisted LBT (RxA-1) and omni- directional LBT (TxED-Omni). Nonetheless, the RxA-1 implementation does not model the overhead of information exchange between the transmitter and receiver. Hence, it is expected that the actual performance of RxA-1 is worse than the simulated one.

- Results from [72] show both flavors of receiver assistance, Rx-Assisted LBT (RxA-2), and Receiver Only LBT (RxA-3), and it outperforms Tx-ED-Omi and Tx-ED-Dir at all loading levels and users percentiles with larger benefits to tail users.

- Results from [56] show gains with receiver assisted LBT for DL and UL in the median as well as tail, primarily at higher loading levels.

- The results show receiver assisted LBT RxA-5 Omni with EDT -67 dBm and RxA-5 Dir with -67 dBm. Results with -67 dBm outperforms TxED-Omni and TxED-Dir as loading level increases.

- The results show comparable performance of RxA-5 Omni and RxA-5 Dir for the baseline gNB antenna configuration.

- As directionality increases at the gNB with more antenna elements, (i.e. when gNB configuration (Mg,Ng,M,N,P) = (1,1,4,8,2) is replaced with (Mg,Ng,M,N,P) = (1,1,8,16,2)), the relative benefits of Rx-Assistance are shown to be larger.

- As silencing threshold is decreased from -67 to -72 dBm, the relative gains of Rx-Assistance increase. At 2 GHz bandwidth, a silencing threshold of -72 dBm is close to noise floor and may not be achieved as ED but may require a sequence detection mechanism.

- Results from [37] show gains with receiver assisted LBT RxA-4-Omni relative to TxED-Omni primarily for uplink, at medium and high loads for all users. For DL, the performance is comparable between RxA-4 Omni and TxED-Omni, except at high load tail, where RxA-4-Omni underperforms.

For Indoor scenario A, following observations were made:

- Results from [72] shows receiver-only LBT (RxA-3) tail UPT and mean UPT gain compared to receiver-assisted LBT (RxA-2) in low, medium, and high traffic loads with InH Open Office channel model and InH mixed channel model.

- Results from source [65] in coexistence scenario with Operator A performing No-LBT and Operator B performing TxED-Omni LBT at -47 dBm EDT show that the operator B performance does not degrade (i.e. no losses observed) as compared to the case when Operator B coexists with another operator using LBT.

- Results from source [65] for dynamic LBT shows that the performance of the network can be improved when the decision to perform LBT is done dynamically per node, as compared to semi-statically operating all nodes with LBT.

One Company submitted results for Indoor Scenario B in [65], which is a smaller indoor scenario with 2 operators and 1 gNB each. Their observations for this case are in line with their observations for Indoor Scenario A.

For comparison of No-LBT with omnidirectional LBT (TxED-Omni) for Indoor Scenario C, source [65], and source [72] show loss for TxED-Omni LBT, source [71] shows roughly comparable performance.

- Results from [65] show worse performance for TxED-Omni LBT relative to No-LBT for both threshold -47 dBm and -68 dBm. The loss is higher for EDT -68 dBm.

- Results from [71] with low load and DL:UL ratio of 50:50 show loss for TxED-Omni LBT over No-LBT. Their medium load DL:UL ratio 5:2 results show gains in DL tail user and UL median user, loss in UL tail user and comparable performance for other cases. Their high load results for DL:UL ratio ~2:1, show small tail gain and median loss for DL and comparable performance for UL.

- Results from [72] show loss for TxED-Omni LBT over No-LBT at -47 dBm EDT for gNB and -32 dBm EDT for UE.

For comparison of omnidirectional LBT (TxED-Omni) with directional LBT (TxED-Dir) for Indoor Scenario C, following observations were made:

- Results from source [72] and [65] with equal ED threshold, Directional sensing (TxED-Dir) and Omni sensing (Tx-ED-Omni) show comparable results.

- Results from source [64] show gains for directional LBT in median users as well as tail users at -68 dBm ED threshold for 100% DL traffic

For comparison of Rx-Assistance LBT schemes with others for Indoor scenario C, the following observations were made:

- Results from [65] results show similar performance of Rx Assistance (RxA-1 -Omni) and TxED-Omni LBT but loss relative to no-LBT at both modelled ED thresholds. There is no benefit of using RxA-1 scheme over TxED-Dir LBT scheme for ED Threshold -47 dBm.

- Another form of Rx-Assistance, referred as, Dyn-RxA is shown by source [65] to provide similar performance as No-LBT for ED Threshold -47 dBm.

- Results from [72] show consistent loss for receiver assistance scheme RxA-2 compared to No-LBT. RxA-2 is shown to outperform TxED-Omni and TxED-Dir for this scenario.

For outdoor scenario B, following observations were made:

- Results from source [65] show loss of TxED-Omni LBT schemes compared to No-LBT, for two ED thresholds -47 and -68 dBm. TxED-Omni LBT with ED Threshold of -68 dBm and -47 dBm has similar performance.

- Results from source [72] shows loss for LBT schemes with respect to no-LBT for 1-site and 7 -site scenarios. Directional and omni LBT are comparable at -47dBm EDT for gNB and -32dBm EDT for UE.

- Results from source [72] show loss of TxED Omni LBT scheme compared to No-LBT for EDT -47 dBm. TxED Omni and TxED-Dir are shown to have comparable performance. Receiver assisted LBT (RxA-2) is seen to improve tail performance and to a small extent median user performance at high loading levels compared to TxED-Omni, and in all other cases seen to have comparable performance. RxA-2 simulated underperforms No-LBT in all cases. These trends hold for 7-site as well as 1-site simulations.

The following flavors of channel access schemes have been modeled.

- No-LBT: No LBT with Dynamic TDD. NR operation with no restrictions on channel access mechanism.

- TxED-omni: Tx side ED Based LBT with omnidirectional sensing, also referred to as ‘Tx Omni LBT’. Baseline LBT with sensing at the transmitter is expected to closely follow the ETSI EN 302 567 [4] based medium access procedure.

- TxED-Dir: Tx side ED Based LBT with directional sensing, also refered to as ‘Tx Directional LBT’.

- Multiple flavors of Rx Assistance have been modelled. The following are list of Rx Assisted LBT flavors:

- RxA-1: Receiver assisted LBT from source [65]. The LBT procedure is evaluated at the receiver instead of transmitter. The LBT result is assumed to be available instantly at the transmitter without accounting any overhead for exchanging this information between the transmitter and the receiver.

- RxA-2: From source [72]. Receiver performs directional LBT but transmitter performs Omni LBT. Further details for RxA-2 are as follows. When UE is the receiver, UE receives an RTS from the gNB. Then, UE sends a "message B" to the gNB with CCA measurements results (dBm value of the measured interference) upon a successful LBT procedure. The latency from the reception of RTS to the transmission of "message B" is calculated equal to 4 slots for 120 kHz SCS and 22 slots for 960 kHz SCS. This includes the required time at the UE side for CCA. Then, gNB transmits PDSCH to the UE. The PDSCH processing time is calculated as 3 slots for 120 kHz and 13 slots for 960 kHz. A CAT4 LBT is performed at the gNB side before RTS transmission. When gNB is the receiver, first gNB performs energy measurement at the directions of the UEs that have UL data. Then, gNB selects the UE with the lowest interference level. After, gNB sends PDCCH to schedule PUSCH transmission of that UE. Finally, PUSCH is transmitted after a successful CAT2 LBT. In our simulations, we have considered the preparation time from PDCCH reception to PUSCH transmission equal to 4 slots for 120 kHz SCS and 22 slots for 960 kHz SCS. A processing time for PUSCH at gNB is not modelled. The transmissions are restricted to Rank 1 for DL as well as UL throughout.

- RxA-3: From source [72]. Only Receiver performs directional LBT procedure. The procedure is similar to RxA-2 except that gNB does not perform any LBT before RTS transmission.

- RxA-4: From source [37]. RTS and CTS type mechanism is deployed after winning contention before transmission. The RTS/CTS type exchange is between serving gNB and the served UEs. The transmitter sends a request, and the receiver feedbacks a confirmation if the request could be successfully decoded. Unlike RTS/CTS mechanism in IEEE 802.11ad, both the request and confirmation do not silence any other node. The processing delay for the RTS/CTS is assumed to be zero. There is no LBT before CTS.

- RxA-5: From source [56]. Rx Assistance takes the form of protecting ongoing transmissions by silencing based on sensing at the transmitters and protecting intended transmission by silencing based on sensing at the receiver. The receiver also assists by sending silencing signals. Omni and directional sensing are applied at all nodes. In the simulated procedure, the ECCA is performed at the gNB followed by an exchange of request/response transmissions.

- Other LBT flavors:

- Dyn-RxA: Dynamic LBT from source [65]: a node operates without LBT unless the receiver experiences a failure in reception due to a drop in SINR, which reflects a presence of interferer. Only then, the node switches to LBT. Besides, when the LBT is switched on, the RAL described in section 2.1.4 of [45] is used.

Table 6.2.X-1 System level simulations setups for indoor scenario A

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Source** | **SCS, Bandwidth** | **DL:UL traffic ratio** | **File size (MB)** | **LBT flavours** | **ED Thresholds (dBm), CW (min,max)** | **Remarks** |
| [65] | 960 kHz / 2 GHz | 1:1 | 27 | No-LBT, TxED-Omni, TxED-Dir, RxA-1, Dyn-RxA, Mixed Coexistence | {-47, -68} for TxED-Omni,  {-47} for TxED-Dir  {-32 for gNB/-41 for UE} for TxED-Dir,  (0,3) | Also: No-LBT and TxED-Omni Coexistence Simulations |
| [72] | {960 kHz / 2 GHz} (InH-Open)  {120 kHz / 400 MHz} (InH mixed) | 1:1 | 27(InH-Open)  8(InH mixed) | No-LBT, TxED-Omni, TxED-Dir, RxA-2, RxA-3 | {-47 for gNB/-32 for UE}/(127,127) | InH-Open, InH Mixed, Rank1 Transmissions |
| [56] | 960 kHz / 2 GHz | 1:1 | 2,8 | TxED-Omni, TxED-Dir, RxA-5-Omni, RxA-5-Dir | {-47, -67,-72}, (0,3) | Two Antenna Config. at gNB |
| [37] | 960 kHz / 2 GHz | 1:1 | 27 | No-LBT, TxED-Omni, TxED-Dir, RxA-4-Omni, RxA-4-Dir | {-47}, (0,3), |  |
| [64] | 960 kHz / 2 GHz  120 kHz / 400 MHz | 1:1  1:0  1:0 | 8  27  27 | TxED-Omni, TxED-Dir, | { -62, -68}, (0,10) | Also: TxED-Dir and TxED-Omni Coexistence Simulations |
| [62] | 960 kHz / 2 GHz | 1:1  1:0 |  | No-LBT, TxED-Omni, TxED-Dir, | {-47}, (0,3) |  |
| [67] | 960 kHz / 2 GHz | 1:1 | 27 | No-LBT, TxED-Omni, TxED-Dir, | {-47}, (0,3) |  |
| [43] | 960 kHz / 2 GHz | 1:1 | 2 | No-LBT, TxED-Omni, TxED-Dir, | {-48, -55, -65}, (0,15) | Two Antenna Config. at UE |

Table 6.2.X-2 System level simulations setups for indoor scenario C

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Source** | **SCS, Bandwidth** | **DL:UL traffic ratio** | **File size (MB)** | **LBT flavours** | **ED Thresholds (dBm), CW (min,max)** | **Remarks** |
| [65] | 960 kHz / 2 GHz | 1:1 | 27 | No-LBT, TxED-Omni, TxED-Dir, RxA-1, Dyn-RxA, , Mixed Coexistence | {-47, -68} for TxED-Omni,  {-47} for TxED-Dir  {-32/-41} for TxED-Dir,  (0,3) | Also: No-LBT and TxED-Omni Coexistence Simulations |
| [72] | 960 kHz / 2 GHz | 1:1 | 27 | No-LBT, TxED-Omni, TxED-Dir, RxA-2, | {-47 for gNB/-32 for UE}, (127,127) | Rank 1, InH-Open |
| [64] | 960 kHz / 2 GHz | 1:0 | 27 | TxED-Omni, TxED-Dir, | {-68} |  |
| [49] | 120 kHz / 400 MHz | 1:0 | 27 | No-LBT, | - |  |
| [54] | 960 kHz / 2 GHz  960 kHz / 400 MHz | 1:1 |  | No-LBT, | - |  |
| [71] | 480 kHz / 400 MHz | 1:1,  5:2,  2:1 | 0.5 | No-LBT, TxED-Omni | {-47} |  |

Table 6.2.X-3 System level simulations setups for outdoor scenario B

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Source** | **SCS, Bandwidth** | **DL:UL traffic ratio** | **File size (MB)** | **LBT flavours** | **ED Thresholds (dBm), CW (min,max)** | **Remarks** |
| [65] | 960 kHz / 2 GHz | 1:1 | 27 | No-LBT, TxED-Omni, | {-47, -68} for TxED-Omni,  (0,3) |  |
| [72] | 960 kHz / 2 GHz | 1:1 | 27 | No-LBT, TxED-Omni, TxED-Dir, RxA-2, | {-47 for gNB/-32 for UE}/(127,127) | 1 Site,  7 Sites |

Table 6.2.X-4 System level simulations setups for indoor scenario B

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Source** | **SCS, Bandwidth** | **DL:UL traffic ratio** | **File size (MB)** | **LBT flavours** | **ED Thresholds (dBm), CW (min,max)** | **Remarks** |
| [65] | 960K/2G | 1:1 | 27 | No-LBT, TxED-Omni, TxED-Dir, RxA-1, Dyn-RxA, Mixed Coexistence | {-47, -68} for TxED-Omni,  {-47} for TxED-Dir  {-32 for gNB/-41 for UE} for TxED-Dir,  (0,3) | No-LBT and TxED-Omni Coexistence Simulations |

# Annex A: Evaluations methodology

## A.1 Link level evaluation assumptions

This subclause describes the link level simulation assumptions used for evaluations. The link level simulation assumption is given in Tables A.1-1. 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 A.1-1: 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. |

## A.2 System level evaluation assumptions

This subclause describes the system level simulation assumptions used for evaluations. The system level simulation assumption is given in Tables A.2-1. The primary objective is evaluation of single operator and multi-operator deployments including study of interference impact and coexistence between nodes. The evaluation KPI(s) include user throughput, latency, average buffer occupancy, ratio of mean served throughput and offered cell throughput, and resource utilization. The secondary objective is to obtain delay spread profiles (and inter-symbol interference statistics) for deployment scenarios of interest. Note that performance impact from delay spread should be conducted in link level simulations, the system level simulations would be used to supplement the findings.

Table A.2-1: System level evaluation assumptions and parameters

| Assumptions | Value |
| --- | --- |
| Carrier Frequency [GHz] | 60 GHz  Optional: 70 GHz |
| Subcarrier Spacing [kHz] | For 2000MHz BW:  - 960 kHz  - optional: 120, 240, 480 kHz  For 400MHz BW:  - 120 kHz  - optional: 240, 480, 960 kHz  Note: Other than value above, companies are encouraged to evaluating using subcarrier spacing values determined to be feasible from LLS study. Values for the subcarrier spacing may be revisited after further investigation from LLS study. |
| Bandwidth [MHz] | 2000 MHz  400 MHz  Note: Channel bandwidth evaluated may be revisited after further investigation. |
| Number of RB | For 2000 MHz:  - N/A (120 kHz),  - N/A (240 kHz),  - 320 (480 kHz) (optional),  - 160 (960 kHz),  - 80 (1920 kHz),  For 400 MHz:  - 256 (120 kHz),  - 128 (240 kHz),  - 64 (480 kHz),  - 32 (960 kHz),  - N/A (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. |
| Deployment Scenario | - Scenario indoor-A (for two operator case)  - Scenario indoor-C (for single operator case)  **Secondary scenarios:**  - Scenario outdoor-B  Optional:  - other scenarios listed below  **Indoor Office:**  **Scenario Indoor-A)** InH open office model:  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.  Optional: single operator deployment in Scenario Indoor-A    **Scenario Indoor-B)** small InH open office model:  Office box 20m x 20 m, 1 BS per operator, 2 operator, BS height at 3m (ceiling), UE height 1m, BS randomly deployed within 10m x 10m virtual box, minimum distance between BS of different operators is 2m.    **Scenario Indoor-C)** InH open office model:  Office box 120m x 50 m, 12 BS per operator, 1 operator, BS height at 3m (ceiling), UE height 1m, BS fixed position, ISD = 20m      **Scenario Indoor-D)** InH open office model:  Office box 120m x 50 m, 6 BS per operator, 2 operator, BS height at 3m (ceiling), UE height 1m, BS fixed position, ISD = 20m  FFS: if the office box scenario can be reduced down to 50m x 50m      **Scenario Indoor-E)** InH open office model:  Office box 120m x 80 m, 3 BS per operator, 2 operator, BS height at 3m (ceiling), UE height 1m, BS fixed position, a=20m, b=40m, c=20m, and d=40m  image001    **Dense Urban:**  **Scenario Outdoor-A)** Dense Urban with 1 layer  Hexagonal grid, single layer, 3 sectors per site, 7 sites locations, BS height 10m, UE height 1.5m, ISD = 150m  FFS: whether ISD needs to be smaller  optional: Reducing deployment size from 7 sites to 1 site with wrap around      **Scenario Outdoor-B)** Dense Urban with 2 layers  Macro layer (sub 7GHz – not necessarily need to be simulated for the 60GHz evaluation):  Hexagonal grid, single layer, 3 sectors per site, 7 sites locations  BS height 25m, UE height 1.5m, ISD = 100m, fixed BS position  Micro layer (above 52.6 GHz):  BS height 10m, UE height 1.5m, 2 operator, 2 BS per hexgrid per operator, random position within macro hexagonal grid per operator, minimum distance between TRP and UE: 10m, minimum distance between micro gNBs’ of the same operator: 10m  optional: Reducing deployment size from 7 sites to 1 site with wrap around.      **Scenario Outdoor-C)** Dense Urban with 1 layer  Hexagonal grid, single layer, 3 sectors per site, 3 sites locations, BS height 10m, UE height 1.5m, ISD = 150m    **Indoor Factory Hall:**  **Scenario Factory-A)** Indoor factory with Dense cluster & low BS (InF-DL)  Grid, 300m x 150m x 10m factor hall  ISD 50m, BS height 1.5m, UE height 1.5m, Typical clutter size 2m, Clutter height 6m, Clutter density 60%  **Scenario Factory-B)** Indoor factory with sparse clutter & High BS (InF-SH)  Grid, 300m x 150m x 10m factor hall  ISD 50m, BS height 8m, UE height 1.5m, Typical clutter size 10m, Clutter height 2m, Clutter density 20% |
| UE distribution | Average of 5 or 10 UE per BS    UE are either 100% indoor or 100% outdoor depending on deployment scenario. |
| Channel Model | **InH open office:**  - gNB-to-gNB and gNB-to-UE links: InH – office channel & PL model from TR38.901, indoor – open office LOS probability from TR38.901 (optional: indoor – mixed office LOS probability from TR38.901)  - UE-to-UE links: InH – office channel & PL model from TR38.901, indoor – mixed office LOS probability from TR38.901    **Dense Urban:**  - gNB-to-gNB and gNB-to-UE links: UMi street canyon channel & PL model from TR38.901  - UE-to-UE links: [outdoor to outdoor D2D channel & PL model from TR36.843 Section A.2.1.2], [(optional: UMi street canyon channel & PL model from TR38.901)]    **Indoor factory:**  - gNB-to-gNB and gNB-to-UE links: InF channel & PL model from TR38.901  - UE-to-UE links: [InF channel & PL model from TR38.901]  Note: 3D distance between an gNB and a UE is applied. 3D distance is also used for LOS probability and break point distance.  Note: channel models in brackets, [ ], are working assumption and may be revisited.  Note: For D2D channel model used for UE-to-UE links companies should report how they scaled the model to 60 GHz. |
| Mobility | 3 km/hr |
| BS Antenna Configuration (Mg,Ng,M,N,P) | For outdoor macro/sectorized scenarios:  (Mg,Ng,M,N,P) = (1,1,8,16,2)  with (0.5 dv, 0.5 dH)  For outdoor micro-layer scenarios:  (Mg,Ng,M,N,P) = (1,3,8,16,2)  with (0.5 dv, 0.5 dH)  Note: 3 Panel single sector gNB with {0,+120,-120} degree boresight orientations. The gNB will only utilize 1 panel at given moment.  For indoor scenarios:  (Mg,Ng,M,N,P) = (1,1,4,8,2) with (0.5 dv, 0.5 dH)  optional: (Mg,Ng,M,N,P) = (1,1,8,16,2) per pol with (0.5 dv, 0.5 dH) |
| BS Antenna Pattern | For outdoor scenarios:  - Antenna power pattern given in Table 7.3-1 of TR38.901  (with exception of antenna element gain)  For indoor scenarios:  - Antenna power pattern given in Table A.2.1-7 of TR38.802 for ceiling mount  (with exception of antenna element gain)  For factory scenarios:  Companies to provide information on the antenna orientation and pattern used. |
| BS Antenna element gain | 5 dBi |
| UE Antenna Configuration (Mg,Ng,M,N,P) | Configuration 1:  (Mg,Ng,M,N,P) = (1,2,2,2,2)  with (0.5 dv, 0.5 dH)  Configuration 2 (optional):  (Mg,Ng,M,N,P) = (1,2,4,4,2)  with (0.5 dv, 0.5 dH)  Note: In both configurations, the 2 panels are back-to-back with panel selection done the at receiver. The UE will only utilize 1 panel at a given moment. |
| UE Antenna Pattern | Antenna power pattern given in Table A.2.1-8 of TR38.802  For indoor factory scenarios:  Boresight orientation should be fixed in all simulation drops  For other scenarios:  Boresight orientation should be randomized between [0°, 360°) in the horizontal plane in each simulation drop  Note: Companies to provide information about boresight orientation (e.g. random orientation, vertical to ground, parallel to ground, etc) |
| UE Antenna element gain | 5 dBi |
| BS Power Limitation | 40 dBm EIRP  Optional: 60 dBm EIRP  Maximum TxP adjusted to meet EIRP limits |
| UE Power Limitation | 25 dBm EIRP with 21 dBm max TxP    Optional: 40dBm EIRP with 21 dBm max TxP |
| BS NF | 7 dB |
| UE NF | 10 dB  Optional: 13dB |
| Transmission Rank | Rank adaptative transmission between Rank 1 and 2 |
| PDCCH Overhead | 2 symbol per slot |
| DMRS Overhead | 1 symbol per slot |
| CSI-RS Overhead | Companies to provide information |
| SRS Overhead | Companies to provide information |
| Other Overhead | Companies to provide information |
| Data Processing Latency | UE processing timeline in microseconds are assumed to be same as 120 kHz SCS PDSCH/PUSCH processing latency  Optional:  UE processing timeline in microseconds are assumed to be half of 120 kHz SCS PDSCH/PUSCH processing latency |
| TDD DL/UL Ratio | Companies to provide information (if applicable) |
| CSI feedback | Ideal feedback |
| Additive Rx EVM | Note: additive Rx EVM values may be revisited after LLS study |
| Traffic Model | FTP Model 3 (27Mbyte file)    Optional:  - Full buffer,  - FTP Model 1 (27, 8 Mbyte file),  - FTP Model 3 (0.5, 2, 8, 16 Mbyte file) |
| UE Receiver | MMSE-IRC |
| Cell selection criteria | Random select from strongest RSRP with 1 dB HO Margin  Note: UE with RSRP below a -71 dBm + 10 log10( bandwidth/2GHz ) are not considered in simulation and not counted toward UE distribution count |
| DL/UL Traffic Ratio | 50% DL, 50% UL    Optional:  100% DL, 0% UL,  80% DL, 20% UL  0% DL, 100% UL |
| Channel access modelling | Companies to report details of LBT procedure and parameters (e.g. ED, CWmax, COT, etc.) if LBT procedure is used in the evaluations. |
| Synchronization Assumption | Companies are asked to provide information on the synchronization assumption made between operators for 2 operator deployment scenarios. |

## A.3 LBT procedure for system level evaluation

This subclause describes the LBT procedure assumed for system level simulation evaluations. Figure A.3-1 shows an illustration of the LBT procedure assumed for system level simulation evaluations. LBT procedures in draft v2.1.20 of EN 302 567 as the baseline system evaluation with LBT [4]. When the node is performing CCA before initiating transmission, during count down, when an observation slot fails energy detect (ED), the counter freezes, and will continue count down 8 μs after the interference is detected to be gone. Any enhancements to ED threshold, contention window sizes, Zmin and Zmax, can be considered as part of the evaluations. The smallest value of Zmax for contention window size is 3, and Zmin is equal to 0.



Figure A.3-1: Illustration of LBT procedure assumed for system level simulation evaluations

# Annex B: Evaluations results

## B.1 Link level evaluation results

*Editor’s Note: This section will be potentially sub-divided into further sub-sections depending on case and/or scenario.*

### B.1.1 Evaluation results for PDSCH/PUSCH

*Editor’s Note: template for the evaluation results is presented as a placeholder for now.*

Table B.1.1-1: LLS template: SINR in dB achieving PDSCH/PUSCH BLER of 10% /1%

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Tdoc /  Source | MCS | Channel | 120KHz /400MHz | 240KHz /400MHz | 480KHz /400MHz | 960KHz /400MHz | 960KHz /2GHz |
| R1-xxxxxxx / Source 1 | 7 | TDL-A, 5ns | X / Y (X for 10% BLER, Y for 1% BLER) |  |  |  |  |
| TDL-A, 10ns |  |  |  |  |  |
| TDL-A, 20ns |  |  |  |  |  |
| CDL-B, 20ns |  |  |  |  |  |
| CDL-B, 50ns |  |  |  |  |  |
| CDL-D, 20ns |  |  |  |  |  |
| CDL-D, 30ns |  |  |  |  |  |
| 16 | TDL-A, 5ns |  |  |  |  |  |
| TDL-A, 10ns |  |  |  |  |  |
| TDL-A, 20ns |  |  |  |  |  |
| CDL-B, 20ns |  |  |  |  |  |
| CDL-B, 50ns |  |  |  |  |  |
| CDL-D, 20ns |  |  |  |  |  |
| CDL-D, 30ns |  |  |  |  |  |
| 22 | TDL-A, 5ns |  |  |  |  |  |
| TDL-A, 10ns |  |  |  |  |  |
| TDL-A, 20ns |  |  |  |  |  |
| CDL-B, 20ns |  |  |  |  |  |
| CDL-B, 50ns |  |  |  |  |  |
| CDL-B, 20ns |  |  |  |  |  |
| CDL-B, 50ns |  |  |  |  |  |
| Additional report/notes:   1. CP type 2. antenna configuration for CDL model 3. waveform in case of PUSCH 4. PTRS configuration 5. DMRS configuration 6. any optional or other assumption/parameters used not as in the baseline | | | | | | |

### B.1.2 Evaluation results for PSS/SSS

*Editor’s Note: template for the evaluation results is presented as a placeholder for now.*

Table B.1.2: LLS template: SINR in dB achieving cell ID detection probability of 90% by one-shot detection from PSS/SSS

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Tdoc /  Source | Channel | 120KHz | 240KHz | 480KHz | 960KHz |
| R1-xxxxxxx / Source 1 | TDL-A, 5ns |  |  |  |  |
| TDL-A, 10ns |  |  |  |  |
| TDL-A, 20ns |  |  |  |  |
| CDL-B, 20ns |  |  |  |  |
| CDL-B, 50ns |  |  |  |  |
| CDL-D, 20ns |  |  |  |  |
| CDL-D, 30ns |  |  |  |  |
| Additional report/notes:   1. frequency offset 2. the number and granularity of the frequency locations 3. antenna configuration for CDL model 4. any optional or other assumption/parameters used not as in the baseline 5. false alarm rate 6. criteria for PSS detection success | | | | |

### B.1.3 Evaluation results for PRACH

*Editor’s Note: template for the evaluation results is presented as a placeholder for now.*

Table B.1.3-1: LLS template: SINR in dB achieving PRACH preamble misdetection probability of 1% and corresponding false alarm probability

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Tdoc /  Source | Channel | 120KHz | 240KHz | 480KHz | 960KHz |
| R1-xxxxxxx / Source 1 | TDL-A, 5ns | X / Y (X for SINR in dB to reach 1% misdetection, Y for corresponding false alarm probability in % at that SINR) |  |  |  |
| TDL-A, 10ns |  |  |  |  |
| TDL-A, 20ns |  |  |  |  |
| CDL-B, 20ns |  |  |  |  |
| CDL-B, 50ns |  |  |  |  |
| CDL-D, 20ns |  |  |  |  |
| CDL-D, 30ns |  |  |  |  |
| Additional report/notes:  1. PRACH format  2. values of  3. antenna configuration for CDL model  4. any optional or other assumption/parameters used not as in the baseline | | | | |

## B.2 System level evaluation results

*Editor’s Note: This section will be potentially sub-divided into further sub-sections depending on case and/or scenario. Template for the evaluation results is presented as a placeholder for now.*

Table B.2-1: System level evaluation results for scenario

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Tdoc /  Source | Cases | | Case 1 | | | Case 2 | | |
| R1-xxxxxxx / Source 1 | Traffic load  Metrics | | Low load  10%~25% BO | Medium load  35%~50% BO | High load  above 55% BO | Low load  10%~25% BO | Medium load  35%~50% BO | High load  above 55% BO |
| DL UPT (Mbps) | 5%ile |  |  |  |  |  |  |
| 50%ile |  |  |  |  |  |  |
| 95%ile |  |  |  |  |  |  |
| mean |  |  |  |  |  |  |
| DL delay (s) | 5%ile |  |  |  |  |  |  |
| 50%ile |  |  |  |  |  |  |
| 95%ile |  |  |  |  |  |  |
| mean |  |  |  |  |  |  |
| UL UPT (Mbps) | 5%ile |  |  |  |  |  |  |
| 50%ile |  |  |  |  |  |  |
| 95%ile |  |  |  |  |  |  |
| mean |  |  |  |  |  |  |
| UL delay (s) | 5%ile |  |  |  |  |  |  |
| 50%ile |  |  |  |  |  |  |
| 95%ile |  |  |  |  |  |  |
| mean |  |  |  |  |  |  |
| Arrival rate (files/s) | |  |  |  |  |  |  |
| 𝜌DL | |  |  |  |  |  |  |
| 𝜌UL | |  |  |  |  |  |  |
| BO | |  |  |  |  |  |  |
| Additional report/notes:  1. LBT procedure and parameters  2. any assumptions/parameters used not as in the agreed baseline  3. Details of case: e.g., single or two operators; no-LBT, omni-directional LBT, directional LBT schemes etc.  4. Other metric(s) and definition if reported  5. Details of COT sharing if used in evaluation | | | | | | | |

# Annex C: Change history

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Change history** | | | | | | | |
| **Date** | **Meeting** | **TDoc** | **CR** | **Rev** | **Cat** | **Subject/Comment** | **New version** |
| 2020-10 |  | R1- R1-2007958 |  |  |  | Draft skeleton TR | V0.0.2 |
| 2020-11 |  | R1-200xxxx |  |  |  | Updated TR based on agreements from RAN1 #103-e. | V0.0.3 |
| 2020-11 | RAN#90e | RP-20xxxx |  |  |  |  | V1.0.0 |