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| Technical Report | |
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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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x the first digit:

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

z the third digit is incremented when editorial only changes have been incorporated in the document.

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.

# 1 Scope

The present document captures the findings of the study item "Study on Expanded and Improved NR Positioning" [7]. The purpose of this technical report is to document the requirements, additional scenarios, evaluations, and technical proposals treated during the study and provide a way forward toward normative work on expanded enhancements to NR positioning in TSG RAN WGs.

# 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 21.905: "Vocabulary for 3GPP Specifications".

[2] 3GPP TR 38.857: "Study on NR positioning enhancements".

[3] 3GPP TR 38.845: "Study on scenarios and requirements of in-coverage, partial coverage, and out-of-coverage NR positioning use cases".

[4] 3GPP TS 22.261: "Service requirements for the 5G system".

[5] 3GPP TR 22.855: "Study on ranging-based services".

[6] 3GPP TS 22.104: "Service requirements for cyber-physical control applications in vertical domains".

[7] RP-222616: "Revised SID on Study on expanded and improved NR positioning".

[8] 3GPP TR 37.885: "Study on evaluation methodology of new Vehicle-to-Everything (V2X) use cases for LTE and NR".

[9] 3GPP TR 36.885: "Study on LTE-based V2X Services".

[10] 3GPP TR 36.843: "Study on LTE Device to Device Proximity Services".

[11] 3GPP TR 38.901: "Study on channel model for frequencies from 0.5 to 100 GHz".

[12] 3GPP TR 38.855: "Study on NR positioning support".

[13] 3GPP TR 38.840: "Study on User Equipment (UE) power saving in NR".

[14] 3GPP TR 38.802: "Study on New Radio Access Technology - Physical Layer Aspects".

[15] 3GPP TR 38.830: "Study on NR coverage enhancements".

[16] 3GPP TS 37.355: "LTE Positioning Protocol (LPP)".

[17] 3GPP TS 38.455: "NR Positioning Protocol A (NRPPa)".

[18] R1-2210831 Evaluation of SL positioning Nokia, Nokia Shanghai Bell

[19] R1-2210900 Finalizing SL positioning evaluation Huawei, HiSilicon

[20] R1-2211011 Evaluation of sidelink positioning performance vivo

[21] R1-2211446 Evaluation results for SL positioning OPPO

[22] R1-2211202 Further performance evaluation for SL positioning CATT, GOHIGH

[23] R1-2211615 Evaluation of SL positioning Sony

[24] R1-2211500 Discussion on evaluation of SL positioning ZTE, CMCC

[25] R1-2211368 Discussion on evaluation of sidelink positioning xiaomi

[26] R1-2211739 SL Positioning Evaluation and Performance Lenovo

[27] R1-2211267 Discussion on evaluation of SL positioning LG Electronics

[28] R1-2211720 Evaluation results for SL positioning InterDigital, Inc.

[29] R1-2212049 Discussion on Evaluation for SL Positioning Samsung

[30] R1-2212121 Sidelink Positioning Evaluation Assumptions and Results Qualcomm Incorporated

[31] R1-2212739 Evaluation of SL positioning Intel Corporation

[32] R1-2212427 Evaluation results and observations on V2X and IIoT use case for sidelink positioning CEWiT

[33] R1-2212512 Evaluation of NR SL positioning and ranging Ericsson

[34] Void

[35] R1-2208517 Discussion on Low Power High Accuracy Positioning Quectel

[36] R1-2208559 Discussion on evaluation on LPHAP Spreadtrum Communications

[37] R1-2208651 Discussion on Low Power High Accuracy Positioning vivo

[38] R1-2208737 Views on LPHAP Nokia, Nokia Shanghai Bell

[39] R1-2208802 Discussion on Low Power High Accuracy Positioning OPPO

[40] R1-2210242 Discussion on Low Power High Accuracy Positioning CATT

[41] R1-2209060 On Low Power High Accuracy Positioning Intel Corporation

[42] R1-2209107 Discussion on Low Power High Accuracy Positioning Sony

[43] R1-2210398 Discussion on low power high accuracy positioning ZTE

[44] R1-2209294 Discussion on Low Power High Accuracy Positioning xiaomi

[45] R1-2209344 Discussion on low power high accuracy positioning CMCC

[46] R1-2209396 LPHAP considerations Lenovo

[47] R1-2209490 Discussions on Low Power High Accuracy Positioning (LPHAP) techniques InterDigital, Inc.

[48] R1-2209739 Discussion on LPHAP Samsung

[49] R1-2209786 Views on low power high accuracy positioning Sharp

[50] R1-2209806 Discussion on LPHAP in idle/inactive state LG Electronics

[51] R1-2209910 Discussion on Low Power High Accuracy Positioning NTT DOCOMO, INC.

[52] R1-2209993 Requirements, Evaluations, Potential Enhancements for Low Power High Accuracy Positioning Qualcomm Incorporated

[53] R1-2210178 Evaluations for Low Power High Accuracy Positioning Ericsson

[54] Void

[55] R1-2208652 Discussion on positioning for RedCap UEs vivo

[56] R1-2208738 Views on Positioning for RedCap UEs Nokia, Nokia Shanghai Bell

[57] R1-2208803 Discussion on Positioning for RedCap UEs OPPO

[58] R1-2208985 Discussion on positioning for RedCap UEs CATT

[59] R1-2209061 Enhancements for positioning for RedCap UEs Intel Corporation

[60] R1-2209108 Considerations on positioning for RedCap UEs Sony

[61] R1-2209153 Discussion on positioning support for RedCap UEs NEC

[62] R1-2209217 Discussion on Positioning for RedCap UE ZTE

[63] R1-2209346 Discussion on RedCap positioning CMCC

[64] R1-2209397 Positioning for RedCap devices Lenovo

[65] R1-2209491 Discussions on positioning for RedCap UEs InterDigital, Inc.

[66] R1-2209590 Discussions on Positioning for RedCap UEs Apple

[67] R1-2209740 Discussion on Positioning for RedCap UEs Samsung

[68] R1-2209787 Views on positioning for RedCap UEs Sharp

[69] R1-2209807 Discussion on positioning support for RedCap UEs LG Electronics

[70] R1-2209911 Discussion on positioning for RedCap UEs NTT DOCOMO, INC.

[71] R1-2209994 Positioning for Reduced Capability UEs Qualcomm Incorporated

[72] R1-2210179 Positioning for RedCap UEs Ericsson

[73] R1-2208455 Discussion on NR carrier phase positioning Huawei, HiSilicon

[74] R1-2208650 Discussion on carrier phase measurement enhancements vivo

[75] R1-2208983 Discussion on improved accuracy based on NR carrier phase measurement CATT

[76] R1-2209215 Discussion on carrier phase measurement based positioning ZTE

[77] R1-2210177 Improved accuracy based on NR carrier phase measurement Ericsson

[78] R1-2212379 Evaluation of SL positioning Fraunhofer IIS, Fraunhofer HHI

[79] R1-2210903 Remaining issues for carrier phase positioning Huawei, HiSilicon

[80] R1-2211014 Discussion on carrier phase measurement enhancements vivo

[81] R1-2211205 Further discussion on improved accuracy based on NR carrier phase measurement CATT

[82] R1-2211312 Views on improved accuracy based on NR carrier phase measurement Nokia, Nokia Shanghai Bell

[83] R1-2211406 Improved positioning accuracy with NR carrier phase measurements Intel Corporation

[84] R1-2211435 Discussions on Carrier Phase Measurement for NR Positioning OPPO

[85] R1-2212520 Discussion on carrier phase measurement based positioning ZTE

[86] R1-2211924 Discussion on OFDM based carrier phase measurement in NR LG Electronics

[87] R1-2212859 Discussion on NR Carrier Phase Measurement Samsung

[88] R1-2212124 Phase Measurements in NR Positioning Qualcomm Incorporated

[89] R1-2212519 Views on NR carrier phase measurement for positioning accuracy enhancement IIT Kanpur, CEWiT

[90] R1-2212515 Improved accuracy based on NR carrier phase measurement Ericsson

[91] R1-2208206 FL Summary #3 Carrier Phase Measurements, Moderator (CATT)

[92] R1-2210904 Remaining issues for LPHAP Huawei, HiSilicon

[93] R1-2211015 Discussion on Low Power High Accuracy Positioning vivo

[94] R1-2211055 Discussions and evaluation of LPHAP enhancements FUTUREWEI

[95] R1-2211206 Further discussion on Low Power High Accuracy Positioning CATT

[96] R1-2211239 Discussion on evaluation and solutions for LPHAP Spreadtrum Communications

[97] R1-2211313 Views on LPHAP Nokia, Nokia Shanghai Bell

[98] R1-2211371 Discussion on Low Power High Accuracy Positioning xiaomi

[99] R1-2211407 On Low Power High Accuracy Positioning Intel Corporation

[100] R1-2211436 Discussion on Low Power High Accuracy Positioning OPPO

[101] R1-2211504 Discussion on low power high accuracy positioning ZTE

[102] R1-2211618 Views on Low Power High Accuracy Positioning Sony

[103] R1-2211688 Discussion on low power high accuracy positioning CMCC

[104] R1-2211730 Discussions on Low Power High Accuracy Positioning (LPHAP) techniques InterDigital, Inc.

[105] R1-2211744 LPHAP considerations Lenovo

[106] R1-2211925 Discussion on LPHAP in idle/inactive state LG Electronics

[107] R1-2211991 Discussion on Low Power High Accuracy Positioning NTT DOCOMO, INC.

[108] R1-2212053 Discussion on LPHAP Samsung

[109] R1-2212125 Requirements, Evaluations, Potential Enhancements for Low Power High Accuracy Positioning Qualcomm Incorporated

[110] R1-2212516 Evaluations for Low Power High Accuracy Positioning Ericsson

[111] R1-2210905 Remaining issues of RedCap positioning Huawei, HiSilicon

[112] R1-2210921 Discussion on Positioning for RedCap UEs Quectel

[113] R1-2211016 Discussion on positioning for RedCap UEs vivo

[114] R1-2211207 Further discussion on positioning for RedCap UEs CATT

[115] R1-2211314 Views on Positioning for RedCap UEs Nokia, Nokia Shanghai Bell

[116] R1-2211408 Enhancements for positioning for RedCap UEs Intel Corporation

[117] R1-2211437 Discussion on Positioning for RedCap UEs OPPO

[118] R1-2212743 Discussion on Positioning for RedCap UE ZTE

[119] R1-2211619 Views on positioning for RedCap UEs Sony

[120] R1-2211689 Discussion on RedCap positioning CMCC

[121] R1-2211732 Discussions on positioning for RedCap UEs InterDigital, Inc.

[122] R1-2211741 Public Safety Personal Protection Equipment (PPE) FirstNet, AT&T, UK Home Office, Erillisverkot, MINISTERE DE L'INTERIEUR, SyncTechno Inc., Softil, Nkom

[123] R1-2211745 Positioning for RedCap devices Lenovo

[124] R1-2211819 On Positioning for RedCap UEs Apple

[125] R1-2211926 Discussion on positioning support for RedCap UEs LG Electronics

[126] R1-2211992 Discussion on positioning for RedCap UEs NTT DOCOMO, INC.

[127] R1-2212054 Discussion on Positioning for RedCap UEs Samsung

[128] R1-2212126 Positioning for Reduced Capabilities UEs Qualcomm Incorporated

[129] R1-2212180 Views on positioning for RedCap UEs Sharp

[130] R1-2212197 The potential solutions for RedCap UEs for positioning MediaTek Inc.

[131] R1-2212368 Discussion on positioning support for RedCap UEs NEC

[132] R1-2212517 Positioning for RedCap UEs Ericsson

[133] R1-2208454 Error source for NR RAT-dependent positioning Huawei, HiSilicon

[134] R1-2210902 Remaining issues for RAT-dependent integrity Huawei, HiSilicon

[135] R1-2208649 Discussion on solutions for integrity of RAT-dependent positioning vivo

[136] R1-2208735 Views on solutions for integrity of RAT-dependent positioning techniques Nokia, Nokia Shanghai Bell

[137] R1-2209214 Discussion on integrity of RAT dependent positioning ZTE

[138] R1-2211502 Discussion on integrity of RAT dependent positioning ZTE

[139] R1-2209488 Discussion on integrity for RAT dependent positioning techniques InterDigital

[140] Void

[141] R1-2212051 Discussion on Integrity of RAT Dependent Positioning Samsung

[142] R1-2210176 Error Sources characterization for integrity of RAT dependent positioning techniques Ericsson

[143] R1-2210174 Evaluation of NR SL positioning and ranging Ericsson

[144] 3GPP TS 23.273: "5G System (5GS) Location Services (LCS); Stage 2".

[145] 3GPP TR 23.700-86: "Study on Architecture Enhancement to support Ranging based services and sidelink positioning".

[146] 3GPP TS 38.305: "Stage 2 functional specification of User Equipment (UE) positioning in NG-RAN".

# 3 Definitions of terms, symbols and abbreviations

## 3.1 Terms

For the purposes of the present document, the terms given in TR 21.905 [1] and the following apply. A term defined in the present document takes precedence over the definition of the same term, if any, in TR 21.905 [1].

**Target UE**: UE to be positioned (in this context, using SL, i.e., PC5 interface).

**Anchor UE**: UE supporting positioning of target UE, e.g., by transmitting and/or receiving reference signals for positioning, providing positioning-related information, etc., over the SL interface.

**Sidelink positioning**: Positioning UE using reference signals transmitted over SL, i.e., PC5 interface, to obtain absolute position, relative position, or ranging information.

**Ranging**: Determination of the distance and/or the direction between a UE and another entity, e.g., anchor UE.

**Sidelink positioning reference signal (SL PRS)**: Reference signal transmitted over SL for positioning purposes.

**SL PRS (pre-)configuration**: (Pre-)configured parameters of SL PRS such as time-frequency resources (other parameters are not precluded) including its bandwidth and periodicity.

**SLPP**: Protocol for Sidelink positioning procedures.

## 3.2 Symbols

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

<symbol> <Explanation>

## 3.3 Abbreviations

For the purposes of the present document, the abbreviations given in TR 21.905 [1], TS 38.305 [146], and the following apply. An abbreviation defined in the present document takes precedence over the definition of the same abbreviation, if any, in TR 21.905 [1].

AGV Automated Guided Vehicle

BW Bandwidth

CFO Carrier Frequency Offset

CP Carrier Phase

CPP Carrier Phase Positioning

DD Double Differential

DL Downlink

GNSS Global Navigation Satellite System

IIoT Industrial Internet of Things

IoT Internet of Things

ITS Intelligent Transportation Systems

KPI Key Performance Indicator

LOS Line-of-Sight

LPHAP Low Power High Accuracy Positioning

NLOS Non-Line-of-Sight

OLPC Open Loop Power Control

OOC Out Of Coverage

PCO Phase Center Offset

PFL Positioning Frequency Layer

PRS Positioning Reference Signal

RAN Radio Access Network

RAT Radio Access Technology

RedCap Reduced Capability

RTK Real Time Kinematic

SD Single Differential

SI Study Item

SID Study Item Description

SL Sidelink

SRS Sounding Reference Signals

TR Technical Report

TS Technical Specification

UE User Equipment

UL Uplink

V2X Vehicle to Everything

WI Work Item

# 4 General descriptions of expanded NR positioning enhancements

In Release 17, 3GPP RAN conducted studies on "NR positioning enhancements" TR 38.857 [2] and "Scenarios and requirements of in-coverage, partial coverage, and out-of-coverage NR positioning use cases" TR 38.845 [3].

The study on "Scenarios and requirements of in-coverage, partial coverage, and out-of-coverage NR positioning use cases" focussed on V2X and public safety use cases with the outcome being captured in TR 38.845 [3]. Additionally, SA1 has developed requirements in TS 22.261 [4] for "Ranging based services" TR 22.855 [5] and has developed positioning accuracy requirements in TS 22.104 [6] for IIoT use cases in out-of-coverage scenarios. There is a need for 3GPP to study and develop sidelink positioning solutions that can support the use cases, scenarios and requirements identified during these activities.

The study on "NR positioning enhancements" TR 38.857 [2] investigated higher accuracy, and lower latency location, high integrity and reliability requirements resulting from new applications and industry verticals for 5G. Some of the enhancements identified during that work have been specified during the Release 17 Work Item on "NR positioning enhancements", but there remain a number of opportunities for enhancement that have not yet been incorporated into the specifications.

Regarding higher accuracy, two promising techniques identified in earlier studies will be considered in Release 18: one is to take the advantage of the rich 5G spectrum to increase the bandwidth for the transmission and reception of the positioning reference signals based on PRS/SRS bandwidth aggregation for intra-band carriers, and the other is to use the NR carrier phase measurements. GNSS carrier phase positioning has been used very successfully for centimetre-level positioning but is limited to outdoor applications. NR carrier phase positioning has the potential for significant performance improvements for indoor and outdoor deployments in comparison with the existing NR positioning methods, as well as shorter latency and lower UE power consumption in comparison with RTK-GNSS outdoors.

Positioning integrity is a measure of the trust in the accuracy of the position-related data and the ability to provide timely warnings based on assistance data provided by the network. The focus in Release 17 work was on GNSS integrity, and for Release 18 it is natural to extend this to address other positioning techniques as well as there are relevant integrity aspects of mission critical use cases that rely on positioning estimates and the corresponding uncertainty estimate. Integrity enables applications to make the correct decisions based on the reported position, e.g., when monitoring a robotic arm to decide whether its arm movement are within allowed limits to ensure safety distances to humans and other objects.

SA1 has introduced requirements for LPHAP (Low Power High Accuracy Positioning) for industrial IoT scenarios including use cases such as massive asset tracking, AGV tracking in industrial factory and person localization in danger zones. The SA1 requirements are for high accuracy and extreme low power consumption with battery life sustainable up to one or more years. A typical scenario of interest is use case 6 as defined TS 22.104 [6], which corresponds to tracking of workpiece (in- and outdoor) in assembly area and warehouse with a target accuracy of <1m, a positioning interval of 15-30 seconds, and a battery life of 6-12 months. While Release 17 NR positioning has introduced support for positioning in RRC\_INACTIVE state, there is a need to evaluate whether the current system allows LPHAP requirements to be met.

Release 17 has specified support for RedCap UEs with reduced bandwidth support and reduced complexity including reduced number of receive chains. Such UEs could support NR positioning functionality but there is a gap in that the core and performance requirements have not been specified for the positioning related measurements performed by RedCap UEs, and no evaluation was performed to see how the reduced capabilities of RedCap UEs might impact eventual position accuracy. This gap is to be investigated by the present SI.

# 5 Sidelink positioning

## 5.0 Study objectives

The scope of the study on solutions for SL positioning is defined in the SID [7] as:

- Scenario/requirements for SL positioning

- Identify specific target performance requirements to be considered for the evaluation based on existing 3GPP work and inputs from industry forums

- Define evaluation methodology with which to evaluate SL positioning for the use cases and coverage scenarios, reusing existing methodologies from sidelink communication and from positioning as much as possible

- Study and evaluate performance and feasibility of potential solutions for SL positioning, considering relative positioning, ranging and absolute positioning:

- Evaluate bandwidth requirement needed to meet the identified accuracy requirements

- Study of positioning methods (e.g., TDOA, RTT, AOA/D, etc) including combination of SL positioning measurements with other RAT dependent positioning measurements (e.g., Uu-based measurements)

- Study of sidelink reference signals for positioning purposes from physical layer perspective, including signal design, resource allocation, measurements, associated procedures, etc, reusing existing reference signals, procedures, etc from sidelink communication and from positioning as much as possible

- Study of positioning architecture and signaling procedures (e.g., configuration, measurement reporting, etc) to enable sidelink positioning covering both UE based and network-based positioning.

## 5.1 Sidelink positioning scenarios and requirements

The following objectives are captured in SID [7] on scenarios and requirements for study of sidelink positioning solutions:

- Coverage scenarios to cover: In-coverage, partial-coverage and out-of-coverage.

- Requirements: Based on requirements identified in TR 38.845 [3] and TS 22.261 [4] and TS 22.104 [6].

- Use cases: V2X (TR 38.845) [3], public safety (TR 38.845) [3], commercial (TS 22.261) [4], IIOT (TS 22.104) [6].

- Spectrum: ITS, licensed

Both PC5-only-based positioning solutions and combination of Uu- and PC5-based positioning solutions are considered for study of sidelink positioning.

Based on the study, from the perspectives of RAN1 and RAN2, both of the following operation scenarios are recommended for normative work:

- Operation Scenario 1: PC5-only-based positioning.

- Operation Scenario 2: Combination of Uu- and PC5-based positioning.

For evaluations, in-coverage and out-of-coverage scenarios are prioritized. Further, for evaluation of V2X and public safety use-cases, at least in-coverage and out-of-coverage scenarios are considered, while for evaluation of IIoT and commercial use-cases, at least in-coverage scenarios are considered.

For evaluations, operation in FR1 bands with channel bandwidths of up to 100 MHz is considered. Additionally, operation in FR2 bands with channel bandwidths of up to 400 MHz is optionally considered.

For evaluations of relative positioning, the horizontal plane is assumed to be parallel to the ground.

For this study, requirements on positioning accuracy are expressed as accuracy requirements in terms of percentiles of UEs for one or more of the following metrics:

- Ranging accuracy, expressed as the difference (error) between the calculated distance/direction and the actual distance/direction in relation to another node

- Relative positioning accuracy, expressed as the difference (error) between the calculated horizontal/vertical position and the actual horizontal/vertical position relative to another node

- Absolute positioning accuracy, expressed as the difference (error) between the calculated horizontal/vertical position and the actual horizontal/vertical position.

It should be noted that exact applicability of specific requirements can be expected to vary across use-cases.

For sidelink based ranging, for a given use-case, the value of the distance requirement for ranging distance accuracy is same as the value identified for horizontal positioning accuracy for relative positioning.

For ranging between two devices, ranging direction accuracy is defined as accuracy of Angle of Arrival (AoA) at a receiving node.

For evaluation of different use-cases for SL positioning, the considered target accuracy requirements are summarized in Table 5.1-1.

Table 5.1-1: Target accuracy requirements for SL positioning

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **SL Positioning KPIs** | **V2X** | **Public Safety** | **IIoT** | **Commercial** |
| Horizontal Positioning Accuracy | Set A (similar to "Set 2" defined in [3]): 1.5 m for 90% of UEs (absolute or relative) | 1 m for 90% of UEs (absolute or relative) | Set A: 1 m for 90% of UEs (absolute or relative) | 1 m for 90% of UEs (absolute or relative) |
| Set B: 0.2 m for 90% of UEs (absolute or relative) |
| Set B (similar to "Set 3" defined in [3]): 0.5 m for 90% of UEs (absolute or relative) |
| Vertical Positioning Accuracy | Set A: 3 m for 90% of UEs (absolute or relative) | 2 m (absolute or relative between 2 UEs) for 90% of UEs | Set A: 1 m for 90% of UEs (absolute or relative) | 2 m for 90% of UEs (absolute or relative) |
| Set B: 2 m for 90% of UEs (absolute or relative) | 0.3 m (relative positioning change for 1 UE) for 90% of UEs | Set B: 0.2 m for 90% of UEs (absolute or relative) |
| Relative Speed | - | Up to 30 km/h | Up to 30 km/h | Up to 30 km/h |
| Angle Accuracy | Set A: Y = ±15° for 90% of the UEs | | | |
| Set B: Y = ±8° for 90% of the UEs | | | |
| NOTE 1: For evaluated SL positioning methods, the performance results in Annex B.1 are described in terms of:  - whether each of the two requirements are satisfied, and  - %-ile of UEs satisfying the target positioning accuracy for a requirement that may not be satisfied with 90%.  NOTE 2: Target positioning requirements may not necessarily be reached for all scenarios and deployments  NOTE 3: All positioning techniques may not achieve all positioning requirements in all scenarios. | | | | |

## 5.2 Potential solutions for sidelink positioning

### 5.2.1 Physical layer aspects for SL positioning solutions

#### 5.2.1.1 Positioning Methods for SL Positioning

As part of the study on potential solutions for sidelink positioning, at least the following positioning methods using SL measurements are identified for possible introduction:

- RTT-type solutions using SL

- This includes single-sided (also known as one-way) RTT and double-sided (also known as two-way) RTT

- May include RTT with one or multiple devices.

- Strive to minimize the changes needed on top of the specification support for single-sided RTT, if any, for the introduction of double-sided RTT.

- NOTE: a UE should be able to support single-sided RTT without having to support double-sided RTT.

- SL-AoA

- This includes both Azimuth of Arrival (AoA) and Zenith of Arrival (ZoA) in the study

- SL-TDOA

- For SL-only positioning, at least for the purpose of absolute positioning estimation of a target UE, SL-TDOA corresponds to a method wherein SL PRS are transmitted from multiple anchor UEs to a target UE (i.e., DL-TDOA-like operation), and/or from a target UE to multiple anchor UEs (i.e., UL-TDOA-like operation).

- Based on the study, it was agreed that both DL-TDOA-like operation and UL-TDOA-like operation should be introduced.

- A UE is not required to support both DL-TDOA-like operation and UL-TDOA-like operation.

- SL-AoD

- SL-AoD is deprioritized against the other methods listed above for possible introduction.

Note that the above identification of methods does not necessarily imply their specification as separate methods nor specification of a unified positioning method for sidelink.

For the study of different positioning methods, the following aspects are considered:

- Definition(s) of the corresponding SL measurements for each method

- Applicability of different positioning methods to absolute or relative positioning or ranging, including whether such categorization is needed to be discussed

- For angle-based methods, antenna configuration consideration(s) using practical UE capabilities

- Per-panel location, if UE uses multiple panels

- UE's mobility, especially for V2X scenarios

- Impact of synchronization error(s) between UEs

- Existing SL measurements (e.g., RSSI, RSRP), and UE ID information etc, may be used.

With regards to the sidelink positioning measurement report, the following aspects are included as part of the study:

- Contents of the measurement report, that may include:

- One or more sidelink positioning measurement(s)

- Timestamp(s) associated with a sidelink positioning measurement

- Quality metric(s) associated with a sidelink positioning measurement

- Identification Information for a sidelink positioning measurement

- Time domain behavior of the measurement report (e.g., one-shot, triggered, aperiodic, semi-persistent, periodic).

Whether sidelink positioning measurements can be higher-layer report and/or a lower-layer report is considered in the study.

With regards to the Positioning methods supported using SL PRS measurements at least the following measurements are agreed to be introduced:

- SL Rx-Tx time difference measurement

- SL RSTD measurement

- SL RSRP measurement

- SL RSRPP measurement

- SL RTOA measurement

- SL Azimuth angle of Arrival (AoA) and SL Zenith angle of Arrival (ZoA) measurement.

#### 5.2.1.2 Physical layer structure and reference signal design for SL positioning

New reference signal designs for SL positioning/ranging, referred to as SL PRS, are studied using the existing PRS/SRS design and SL design framework as starting points.

For sequence design for the new reference signal for SL PRS, pseudo-random sequence, using existing DL-PRS sequence as a starting point, is identified as the preferred choice.

With regards to the numerologies of the SL PRS, the study is limited to those supported for NR Sidelink.

As part of the study, at least the following aspects are considered: Sequence design, frequency domain pattern, time domain pattern (e.g., number of symbols, repetitions, etc), time domain behavior, configuration/triggering/activation/de-activation of the SL PRS, AGC time, Rx-Tx turnaround times, supportable bandwidth(s), multiplexing options with other SL channels, and randomization/orthogonalization options.

On the physical structure of SL PRS, a frequency domain pattern following a comb-N design is studied, at least including the following:

- N>=1 (where N=1 corresponds to full RE mapping pattern)

- Fully staggered SL PRS pattern (e.g., M symbols of SL PRS with comb-N with M=N and, at each symbol a different RE offset is used), Partially staggered SL PRS pattern (e.g., M symbol(s) of SL PRS with comb-N, with M<N, at each symbol a different RE offset is used), Unstaggered SL PRS patterns (e.g., M symbol(s) of SL PRS with comb- N, at each symbol a same RE offset is used, N > 1)

- Of the above, fully and partially staggered patterns are further prioritized.

- The number of symbols of SL PRS within a slot

- Any relation to the comb-N option

- RE offset pattern repetitions within a slot

With regards to the frequency and time domain pattern of a SL PRS resource within a slot, a SL PRS resource has the following characteristics:

- On the value N (comb size) and the number M of SL PRS symbols within a slot excluding the symbol(s) used for AGC training / Rx-Tx turnaround:

- At least the following values are considered as potential candidate values: N = {1,2,4,6,8,12}

- The values considered as potential candidate values for M need further consideration during normative work.

- Whether to consider N>12 as a potential candidate value(s) will be considered further during normative work.

- The symbols of a SL PRS resource within a slot are consecutive symbols

- Whether to support consecutive and/or non-consecutive symbols for shared resource pool can be considered further during normative work.

- Details of RE-Offset sequence within a SL PRS resource, including whether to have in the end of the SL PRS pattern a symbol with the same RE-offset as the first symbol, for phase-tracking purpose, can be considered further during normative work.

For the new SL PRS design, the following are further studied:

- Number of symbol(s) for AGC and/or Rx-Tx turnaround time.

- Conditions under which AGC training and/or Rx-Tx turnaround time are needed.

#### 5.2.1.3 Physical layer procedures for SL positioning

On the configuration/ activation/ deactivation/ triggering/ reservation of SL PRS, the study focused on the following options, with considerations on flexibility, overhead, latency, and reliability:

- Option 1: High-layer-only signaling involvement in the SL PRS configuration.

- No Lower layer involvement, e.g., SL-MAC-CE or SCI or DCI, for the activation or the triggering of a SL PRS.

- Based on the study, this option may correspond to:

- A SL PRS configuration that is a single-shot or multiple shots.

- A high-layer configuration that may be received from an LMF, a gNB, or a UE.

- Option 2: High-layer and lower-layer signaling involvement in the SL PRS configuration.

- Lower-layer may correspond to SL-MAC-CE, or SCI, or DCI.

- For example, high layer signaling can be used for SL PRS configuration and lower layer signaling can may be used for initiating SL positioning and/or configuration/triggering/activating/deactivating/indicating and potential resource indication/reservation transmission of SL PRS.

Regarding resource allocation for SL PRS, at least the following schemes are studied:

**- Scheme 1**: Network-centric operation SL PRS resource allocation (e.g., similar to a legacy Mode 1 solution)

- The network (e.g., gNB, LMF, gNB & LMF) allocates resources for SL PRS

**- Scheme 2**: UE autonomous SL PRS resource allocation (e.g., similar to legacy Mode 2 solution)

- At least one of the UE(s) participating in the sidelink positioning operation allocates resources for SL PRS

- Applicable regardless of the network coverage

- Potential mechanisms, if needed, for SL PRS resource coordination across a number of transmitting UEs (e.g., Inter-UE Coordination (IUC)-like solutions) can be considered further during normative work.

Regarding Scheme 1 SL PRS resource allocation, a transmitting UE receives a SL PRS resource allocation signaling from the network. One or both of the following options are considered further for the corresponding signaling:

- Opt. 1: Through higher layers from the LMF

- Opt. 2: Through dynamic grants, or via configurations of configured grant type 1 or type 2 from gNB.

Regarding Scheme 2 SL PRS resource allocation, at least the following aspects are studied:

- Resource selection mechanism for SL PRS

- Inter-UE coordination

- Aspects for congestion control mechanisms for SL PRS.

For Scheme 2 SL PRS resource allocation, one or both of the following options may be supported during normative work:

- Option 1: A sensing-based resource allocation

- Option 2: A random resource selection

- For either Option 1 or 2, the legacy designs for UE autonomous resource allocation should be used as a starting point and potential enhancements that may be needed may be considered during the normative work.

Additionally, on SL positioning resource allocation, the following alternatives are studied:

- Alt. 1: Only dedicated resource pool(s) can be (pre-)configured for SL PRS

- For dedicated resource pool(s) for SL positioning, at least the following details are agreed to be considered:

- which slots can be used, SL frame structure, SL positioning slot structure, multiplexing of SL PRS with control information (if included in the same slot),

- positioning measurement report,

- whether a dedicated frequency allocation (e.g., layer/BWP) is needed for SL PRS,

- resource allocation procedure(s) of SL PRS,

- NOTE: This option may or may not include control information (i.e., configuration/ activation/ deactivation/ triggering of SL PRS) for the purpose of SL positioning operation.

- Alt. 2: Either dedicated resource pool(s) and/or a shared resource pool(s) with sidelink communication can be (pre-)configured for SL PRS

- For shared resource pool(s) for SL positioning, at least the following details are considered:

- Co-existence between SL communication and SL positioning, backward compatibility

- Multiplexing considerations of SL PRS with other PHY channels (PSCCH, PSSCH, PSFCH) and any modifications in the SL-slot structure.

- NOTE: whether other signals/channels can be present in the dedicated resource pool can be considered further during the normative work.

With regards to the SL Positioning resource allocation, it was agreed that either dedicated resource pool(s) and/or a shared resource pool(s) with sidelink communication can be (pre-)configured for SL PRS.

- NOTE: this does not imply that the design is the same for both types of resources pools.

- NOTE: shared resources pool(s) should be supported with backward compatibility.

A dedicated SL PRS resource pool is (pre-)configured in the only SL BWP of a carrier.

The following options are considered for multiplexing of other channels in a dedicated resource pool for SL positioning in addition to SL PRS:

- Opt. 1: No other channel can be included beyond SL PRS

- Opt. 2: PSCCH which carries SCI associated with SL PRS transmission(s) is included

- Opt. 3: PSCCH which carries SCI associated with SL PRS transmission(s) and PSSCH associated with SL PRS transmission(s) are included

- Definition of "PSSCH associated with SL PRS transmission(s)" can be considered further during normative work.

At least for a dedicated resource pool for SL positioning, the following alternatives are studied for subsequent down-selection:

- Alt. 1: The bandwidth of SL PRS can be same or smaller than that of the resource pool.

- Alt. 2: The bandwidth of SL PRS is the same as that of the resource pool.

- Bandwidth of SL PRS transmission for a shared resource pool can be considered further during normative work.

For SL Positioning resource (pre-)configuration in a shared resource pool with Rel-16/17/18 sidelink communication, backward compatibility with legacy Rel-16/17 UEs should be ensured.

With regards to SL signaling of the reservation/indication of SL PRS resource(s) for dedicated resource pool and shared resource pool for positioning:

- SCI can be used for reserving/indicating one or more SL PRS resource(s)

- NOTE: This does not imply that only SCI is being used. Higher layer signaling may be used for the purpose of indicating a part of the SL PRS configuration.

- Whether SCI is single stage SCI or two stage SCI can be considered further during normative work.

- Use of SL-MAC-CE or other higher-layer signaling for SL PRS resource reservation/indication can be considered further during normative work.

The granularity of time-domain resource allocation for SL PRS transmission is studied.

The following options for time-domain resource assignments and associated Tx UE behavior for SL PRS transmissions are studied:

- Periodic SL PRS

- SL PRS is transmitted periodically with a transmission periodicity.

- Any additional details, including whether or not higher layers can start/stop transmission, can be considered further during normative work.

- Semi-persistent SL PRS

- SL PRS is transmitted periodically with a transmission periodicity after activation and until deactivation.

- Aperiodic SL PRS

- SL PRS is transmitted at least once after either triggering or request.

- Applicability of the above options to SL PRS resource allocation schemes 1 and 2 respectively can be considered further during normative work.

- Details of Rx UE behavior can be separately discussed during normative work.

- Mechanism(s) to be used for activation/deactivation/triggering can be considered further during normative work.

Resource allocation for SL-Positioning measurement reports is also included in the study.

Power control mechanisms for SL PRS transmission, including their necessity, are considered in the study. Based on the study, it was agreed that at least Open Loop Power Control (OLPC) should be introduced during the normative work.

### 5.2.2 Potential architecture and signaling procedures for sidelink positioning

5.2.2.1 Potential architecture for SL positioning

Sidelink positioning in-coverage, partial coverage and out-of-coverage scenarios may be supported. In partial coverage scenarios, either of UEs including target UE and one or multiple anchor UEs may be OOC, but with at least one UE being in coverage.

The architecture and signaling procedures are studied to support Operation Scenarios 1 and 2 involving PC5-only-based positioning and combination of Uu- and PC5-based positioning respectively.

NOTE: How to enable the procedures/signaling for supporting SL positioning in partial coverage will be further discussed in normative work.

RAN2 follow SA2 on the architecture, including the possibility of a UE as a location server. RAT-independent SL positioning is not considered in this release. RAN2 waits for SA2 on the triggering of the positioning procedures from upper layers.

The current NG-RAN positioning architecture can in principle be re-used to support Sidelink Positioning in in-coverage and partial coverage scenarios.

5.2.2.2 Sidelink Positioning Protocol (SLPP)

With regards to the sidelink positioning procedures between UEs, SLPP is introduced to support at least the following functionalities:

- SL Positioning Capability Transfer

- SL Positioning Assistance Data exchange

- SL Location Information Transfer

- Error handling

- Abort

The cast type for SLPP signaling is studied, including unicast, groupcast and broadcast.

Unicast/one-to-one operation is assumed as baseline for exchange of SLPP signaling between UEs. Unicast SLPP session-based operation is supported. At least "centralized" operation is supported, i.e., operation where one UE performs range and/or position calculations based on measurement/location information relating to itself and/or other UEs. It is feasible to send at least the following positioning signaling for groupcast/broadcast (in addition to unicast) from RAN2's perspective:

- SL positioning capability

- SL positioning assistance data

Location information is not excluded and can be further considered in normative work.

RAN2 will further discuss in normative work:

- The security issues (e.g., requirements for ciphering and/or integrity) on specific information of SL positioning capability and assistance data in groupcast/broadcast.

- The use cases for applying groupcast/broadcast.

Both session-based and session-less operation for sidelink positioning signaling are studied.

Sidelink positioning supports a session-based concept in SLPP, in which signaling messages within a session can be associated with one another by the involved UEs. The relationship to upper-layer designs from SA2 can be discussed during normative work.

Whether to also support session-less operation and what aspects of session-based operation would not be included can be studied further during normative work.

At least in the case that positioning methods are supported that do not require a mutual exchange of SLPP messages associated with one another among UEs, SLPP session-less operation can be supported. If session-less operation can be operated with security can be studied further during normative work.

If it is determined to support group positioning, it is feasible to perform at least ranging with the estimate calculation at multiple UEs.

SLPP is a separate ASN.1 module from LPP (this does not necessarily imply whether it is included in TS 37.355 [16]).

For the transport layer of SLPP, RAN2 agrees to down select between PDCP and PC5-U.

5.2.2.3 Signaling between UE and LMF

The potential impact to LPP for the support of sidelink positioning procedures between UE and LMF is studied. Protocol between UE and LMF for hybrid PC5+Uu positioning and PC5-only positioning in-coverage will be down-selected from the following options during normative work.

- Extension of LPP, whereby new signaling is to be defined to support hybrid Uu and PC5 based positioning, i.e., extend the existing LPP to support sidelink based positioning between UE and LMF

- Enhancement of LPP whereby SLPP signaling can be transported within LPP transparently, i.e., use the newly defined SLPP to support sidelink based positioning and use the existing LPP to support Uu based positioning; and the SLPP is carried as a container in LPP

- Use of SLPP between the UE and the LMF

The details of functionalities of LMF for supporting SL positioning will be discussed in normative work.

## 5.3 Summary of sidelink positioning evaluations

### 5.3.1 Evaluation of bandwidth requirements to meet identified accuracy requirements

The methodology for the evaluation of SL positioning can be found in Annex A.1.

The performance analysis for Rel-18 SL positioning shows that, with increasing of bandwidth of SL PRS, the positioning accuracy improves for both absolute positioning and relative positioning/ranging for all evaluated scenarios.

For V2X use case in highway scenario, 14 sources ([19], [20], [21], [22], [23], [24], [26], [27], [29], [30], [31], [32], [33], [78]) provided simulation results for FR1, and 2 sources ([27], [32]) provided simulation results for FR2.

- For absolute horizontal accuracy, the results were provided by 14 sources. 12 out of 14 sources show that, the target requirement Set A can be achieved, and 9 out of 14 sources show that the target requirement Set B cannot be achievable even with 100MHz.

- The requirement 1.5m@90% (Set A)

- is achieved with 20MHz bandwidth in contributions from 2 sources ([19], [24]),

- where Joint Uu/SL positioning is used in contributions from ([19], [24])

- and is achieved with at least 40MHz bandwidth in contributions from 4 sources ([19], [22], [27], [29]),

- where SL-only positioning is used in contribution from ([19])

- and is achieved with at least 100MHz bandwidth in contributions from 8 sources ([20], [21], [23], [24], [26], [78], [32], [33]),

- where SL-only positioning is used in contribution from ([24])

- where SL-TDOA technique is used in contribution from ([26])

- and is NOT achieved with 100MHz bandwidth in contributions from 3 sources ([26], [30], [31])

- where two anchors SL AoA technique is used in contribution from ([26])

- and is achieved with 200MHz bandwidth in FR2 in contribution from 1 source ([32]).

- The requirement 0.5m@90% (Set B)

- is achieved with at least100MHz in contributions from 5 sources ([19], [22], [24], [29], [78]),

- where Joint Uu/SL positioning is used in contribution from ([24])

- and is NOT achieved with100MHz bandwidth in FR1 or 400MHz in FR2 in contributions from 9 sources ([20], [21], [23], [24], [26], [30], [31], [32], [33]),

- where SL-only positioning is used in contribution from ([24])

- and is NOT achieved with 200MHz bandwidth in FR2 in contribution from 1 source ([32])

- and is achieved with 400MHz bandwidth in FR2 in contribution from 1 source ([27]).

- For absolute vertical accuracy, the results were provided by 1 source out of 14 sources.

- The requirement 3m@90% (Set A)

- is achieved with at least 100MHz bandwidth by using Joint Uu/SL positioning in contribution from 1 source ([24])

- and is NOT achieved with 100MHz bandwidth by using SL-only positioning in contribution from 1 source ([24]).

- The requirement 2m@90% (Set B)

- is achieved with 100MHz bandwidth by using Joint Uu/SL positioning in contribution from 1 source ([24])

- and is NOT achieved with 100MHz bandwidth by using SL-only positioning in contribution from 1 source ([24]).

- For relative horizontal accuracy, the results were provided by 7 sources out of 14 sources. The performance of relative horizontal accuracy is worse than that of distance accuracy of ranging mainly due to additional angle estimation error. 5 out of 7 sources show Set A can be achieved with at least 100MHz especially for the cases with smaller X values or RSU assist, and 5 out of 7 sources show that Set A cannot be met with 100MHz PRS bandwidth especially for the cases with larger X values or without RSU assist. All 7 sources show Set B cannot be met even by 100MHz in the case without RSU-UE positioning.

- The requirement 1.5m@90% (Set A)

- is achieved with 20MHz bandwidth in contribution from 1 source ([26])

- X = 25m in contribution from ([26]) where RSU deployment is used for performing relative positioning

- is achieved with at least 40MHz bandwidth in contributions from 2 sources ([19], [22])

- X = 20m in contribution from ([22])

- X = 50m in contribution from ([19]) where RSU deployment is additionally used for performing relative positioning

- and is achieved with at least 100MHz bandwidth in contributions from 5 sources ([19], [22], [24], [26], [32])

- X = 25m in contribution from ([22])

- X = 50m in contribution from ([24])

- X = 25m, 50m and 100m in contribution from ([26]) where RSU deployment is used for performing relative positioning

- X = 150m in contributions from ([19]), where BS or RSU deployment is additionally used for performing relative positioning

- X = 200m in contribution from ([32])

- and is NOT achieved with 100MHz bandwidth in contributions from 5 sources ([19], [20], [22], [23], [24])

- X = 50m and 150m in contribution from ([19])

- X = 25m, 50m, and 100m in contribution from ([20])

- X = 100m and 150m in contribution from ([22])

- X = 50m, 100m and 150m in contribution from ([23])

- X = 150m and 300m in contribution from ([24])

- The requirement 0.5m@90% (Set B)

- is achieved with at least 100MHz bandwidth in contributions from 2 sources ([19], [26])

- X = 50m in contribution from ([19]) where RSU deployment is additionally used for performing relative positioning

- X = 25m in contribution from ([26]) where RSU deployment is used for performing relative positioning

- is NOT achieved with 100MHz bandwidth in FR1 or 400MHz in FR2 in contributions from 7 sources ([19], [20], [22], [23], [24], [26], [32]).

- For distance accuracy of ranging, the results were provided by 12 out of 14 sources. 7 out of 12 sources show that the target requirement Set A can be achievable by 20MHz, and 7 out of 12 sources show that the target requirement Set B cannot be achieved with 100MHz bandwidth.

- The requirement 1.5m@90% (Set A)

- is achieved with 20MHz bandwidth in contributions from 5 sources ([19], [20], [22], [24], [27])

- X = 50m and 150 in contribution from ([19])

- X = 25m, 50m, and 100m in contribution from ([20])

- X = 100m and 150m in contribution from ([22])

- X = 50m, 100m, 150m, 200m and 300m in contribution from ([24])

- X = 80m and 160m in contribution from ([27])

- and is achieved with at least 40MHz bandwidth in contribution from 2 sources ([22], [23])

- X = 20m and 25m in contribution from ([22])

- X = 50m in contribution from ([23])

- and is achieved with at least 100MHz bandwidth in contributions from 7 sources ([21], [23], [26], [30], [31], [32])

- X = 50m, 100m and 150m in contribution from ([21])

- X = 50m in contribution from ([23])

- X = 100m in contribution from ([26])

- X = 200 m in contribution from ([30], [32])

- X = 50m and 100m in contribution from ([31]).

- The requirement 0.5m@90% (Set B)

- is achieved with at least 40MHz in contributions from 2 sources ([19], [20])

- X = 50m in contribution from ([19])

- X = 25m, 50m, and 100m in contribution from ([20])

- and is achieved with at least 100MHz in contributions from 4 sources ([19], [22], [23], [24])

- X = 150m in contribution from ([19])

- X = 25m, 100m and 150m in contribution from ([22])

- X = 50m in contribution from ([23])

- X = 50m, 100m, 150m, 200m and 300m in contribution from ([24])

- and is NOT achieved with 100MHz bandwidth in contributions from 7 sources ([21], [23], [26], [27], [30], [31], [32])

- X = 50m, 100m and 150m in contribution from ([21])

- X = 100m and 150m in contribution from ([23])

- X = 100 m in contribution from ([26])

- X = 80m and 160m in contribution from ([27])

- X = 200 m in contributions from ([30], [32])

- X = 50m and 100m in contribution from ([31])

- and is achieved with at least 200MHz in FR2 in contribution from 1 source ([32])

- X = 200 m in contribution from ([32]).

- For angle accuracy of ranging, the results were provided by 6 sources out of 14 sources. All 6 sources show that both the target requirement Set A and Set B can be achieved by 20MHz.

- The requirement 15°@90% (Set A)

- is achieved with 20MHz bandwidth in contributions from 6 sources ([19], [20], [22], [23], [24], [26]),

- X = 50m and 150m in contribution from ([19]), where RSU deployment is additionally used for X=150m for performing ranging

- X = 25m, 50m, and 100m in contribution from ([20])

- X = 20m, 100m and 150m in contribution from ([22])

- X = 50m, 100m and 150m in contribution from ([23]).

- The requirement 8°@90% (Set B)

- is achieved with 20MHz in contributions from 4 sources ([19], [23], [24], [26])

- X = 50m and 150m in contribution from ([19]), where RSU deployment is additionally used for X=150m for performing ranging

- X = 50m, 100m and 150m in contribution from ([23])

- and is achieved with at least 40MHz in contributions from 2 sources ([20], [22])

- X = 50m, and 100m in contribution from ([20])

- X = 20m, 100m and 150m in contribution from ([22]).

- NOTE: For each SL PRS bandwidth, the above observations are based on the best performance from each source.

- NOTE: For the relative positioning accuracy or distance accuracy of ranging, X is the maximum distance between UEs for performing relative positioning or ranging.

- NOTE: Super resolution is used by sources ([19], [20], [22], [23], [24], [26], [27], [31], [32]), and is not used by sources ([21], [27], [29], [78], [30]).

For V2X use case in Urban grid scenario, 11 sources ([19], [20], [21], [22], [23], [24], [25], [26], [30], [31], [32]) provided simulation results for FR1, and 1 source ([32]) provided simulation results for FR2.

- For absolute horizontal accuracy, the results were provided by 9 out of 11 sources. 7 out of 9 sources show that target requirements Set A cannot be achieved with 100 MHz, and 9 sources show that target requirements Set B cannot be achieved with 100 MHz.

- The requirement 1.5m@90% (Set A)

- is achieved with 100MHz by using Joint Uu/SL positioning in contribution from 3 sources ([24], [30], [32]),

- where LOS-only links are used in contribution from ([32])

- and is NOT achieved with 100MHz bandwidth in contributions from 7 sources ([19], [20], [21], [22], [24], [26], [31])

- where SL-only positioning is used in contribution from ([24])

- where two anchors SL AOA positioning is used in contribution from ([26]).

- The requirement 0.5m@90% (Set B)

- is achieved with at least 100MHz by using Joint Uu/SL positioning in contribution from 1 source ([24]),

- and is NOT achieved with 100MHz bandwidth in FR1 or 400MHz in FR2 in contributions from 9 sources ([19], [20], [21], [22], [24], [26], [30], [31], [32])

- where SL-only positioning is used in contribution from ([24])

- where LOS-only links are used in contribution from ([32]).

- For Relative horizontal accuracy, the results were provided by 6 out of 11 sources. The performance of relative horizontal accuracy is worse than that of distance accuracy of ranging mainly due to additional angle estimation error. 5 out of 6 sources show that the target requirement Set A can be achieved by 100MHz especially for the cases with smaller X values. All 6 sources show that the target requirement set B is not achieved even by 100MHz.

- The requirement 1.5m@90% (Set A)

- is achieved with 20MHz bandwidth in contribution from 2 sources ([26], [32])

- X = 25m and 50m in contribution from ([26]) where RSU deployment is used for performing relative positioning

- X = 250m and LOS-only links are used in contribution from ([32])

- and is achieved with at least 100MHz bandwidth in contributions from 4 sources ([19], [22], [23], [26])

- X = 10m and 50m in contribution from ([19])

- X = 10m in contributions from ([22], [23])

- X = 25m, 50m and 100m in contribution from ([26])

- and is NOT achieved with 100MHz bandwidth in contributions from 3 sources ([20], [22], [23])

- X = 10m, 25m, and 50m in contribution from ([20])

- X = 25m in contribution from ([22])

- X = 50m in contribution from ([23]).

- The requirement 0.5m@90% (Set B)

- is achieved with at least100MHz bandwidth in contribution from 1 source ([26])

- X = 25m in contribution from ([26]) where RSU deployment is used for performing relative positioning

- is NOT achieved with 100MHz bandwidth in FR1 or 400MHz in FR2 in contributions from 6 sources ([19], [20], [22], [23], [26], [32])

- X = 10m, 30m and 50m in contribution from ([23])

- X = 50m and 100m in contribution from ([26]) where RSU deployment is used for performing relative positioning

- X = 250m and LOS-only links are used in contribution from ([32]).

- For distance accuracy of ranging, the results were provided by 11 sources. 6 out of 11 sources show that the target requirement Set A can be achieved by 20MHz or 40MHz. 7 out of 11 sources show that the target requirement Set B cannot be achieved by 100MHz.

- The requirement 1.5m@90% (Set A)

- is achieved with at least 20MHz in contributions from 4 sources ([20], [22], [26], [32])

- X = 25m in contribution from ([20])

- X = 25m in contribution from ([22])

- X = 100m in contribution from ([26])

- X = 250m in contribution from ([32]) where RSU deployment is additionally used for performing distance ranging and LOS-only links are used

- and is achieved with at least 40MHz in contributions from 2 sources ([24], [25])

- X = 20m and 30m in contribution from ([24])

- X = 20m, 50m and 100m in contribution from ([25])

- and is achieved with at least 100MHz in contributions from 4 sources ([19], [21], [23], [30])

- X = 10 and 50m in contribution from ([19])

- X = 50m, 100m and 150m in contribution from ([21])

- X = 10m and 30m in contribution from ([23])

- X = 30m in contribution from ([30])

- and is NOT achieved with 100MHz bandwidth in contributions from 3 sources ([20], [24], [31])

- X = 50m and 100m in contribution from ([20])

- X = 50m, 80m and 100m in contribution from ([24])

- X = 50m, 100m in contribution from ([31])

- and is achieved with at least 200MHz in FR2 in contribution from 1 source ([32])

- where LOS-only links are used in contribution from ([32]).

- The requirement 0.5m@90% (Set B)

- is achieved with at least 20MHz in contribution from 1 source ([32])

- X = 250m and LOS-only links are used in contribution from ([32])

- and is achieved with at least 100MHz in contributions from 4 sources ([19], [22], [23], [25])

- X = 10m and 50m in contribution from ([19])

- X = 10m and 25m in contribution from ([22])

- X = 10m in contribution from ([23])

- X = 20m, 50m, 100m in contribution from ([25])

- and is NOT achieved with 100MHz bandwidth in FR1 or 400MHz in FR2 in contributions from 7 sources ([20], [21], [23], [24], [26], [30], [31])

- X = 30m and 50m in contribution from ([23])

- X = 30m in contribution from [30])

- and is NOT achieved with at least 200MHz in FR2 in contribution from 1 source ([32])

- where LOS-only links are used in contribution from ([32]).

- For angle accuracy of ranging, the results were provided by 6 out of 11 sources. 5 out of 6 sources show that the target requirement Set A can be achieved with 20MHz or 40MHz, and 4 out of 6 sources show that the target requirement Set B cannot be achieved with 100MHz.

- The requirement 15°@90% (Set A)

- is achieved with 20MHz in contributions from 4 sources ([19], [23], [25], [26])

- X = 10 and 50m in contribution from ([19])

- X = 10m, 30m and 50m in contribution from ([23])

- Optional antenna configuration is used and X = 20m in contribution from ([25])

- X = 50m and 100m in contribution from ([26])

- and is achieved with 40MHz in contributions from 2 sources ([22], [25])

- X = 10m and 25m in contribution from ([22])

- Optional antenna configuration is used and X = 50m or 100m in contribution from ([25])

- and is NOT achieved with 100MHz bandwidth in contributions from 2 sources ([20], [25]).

- The requirement 8°@90% (Set B)

- is achieved with 20MHz in contribution from 1 source ([26])

- X = 50m and 100m in contribution from ([26])

- and is achieved with 40MHz in contribution from 1 source ([19])

- X = 10m and BS is additionally used for performing ranging in contribution from ([19])

- and is achieved with at least 100MHz in contribution from 3 sources ([19], [23], [25])

- X = 10m and 50m in contribution from ([19])

- X = 10m and 30m in contribution from ([23])

- Optional antenna configuration is used and X = 20m in contribution from ([25])

- and is NOT achieved with 100MHz bandwidth in contributions from 4 sources ([20], [22], [23], [25])

- X = 50m in contribution from ([23]).

- NOTE: For each SL PRS bandwidth, the above observations are based on the best performance from each source.

- NOTE: For the relative positioning accuracy or distance accuracy of ranging, X is the maximum distance between UEs for performing relative positioning or ranging.

- NOTE: Super resolution is used by sources ([19], [20], [22], [23], [24], [25], [26], [31], [32]), and is not used by sources ([21], [30]).

For Public safety use case, 3 sources ([19], [24], [30]) provided simulation results for FR1.

- For absolute horizontal positioning accuracy, the results were provided by 3 sources.

- The requirement 1m@90%

- is achieved with at least 100MHz in contribution from 1 source ([24])

- is NOT achieved with at least 40MHz in contribution from 1 source ([30])

- and is NOT achieved with 100MHz in contribution from 1 source ([19]).

- For Relative horizontal accuracy, the results were provided by 1 out of 3 sources.

- The requirement 1m@90%

- is achieved with at least 100MHz in contribution from 1 source ([19])

- X = 20m in contribution from ([19]).

- For distance accuracy of ranging, the results were provided by 3 sources.

- The requirement 1m@90%

- is achieved with at least 40MHz in contribution from 1 source ([19])

- X = 20m in contribution from ([19])

- is achieved with at least 100MHz in contribution from 1 source ([24])

- X = 50m and 100m in contribution from ([24])

- is NOT achieved with at least 40MHz in contribution from 1 source ([30]).

- For angle accuracy of ranging, the results were provided by 2 out of 3 sources.

- The requirement 15°@90% (Set A)

- is achieved with at least 10MHz in contribution from 1 source ([19])

- X = 20m in contribution from ([19])

- is achieved with 20MHz in contribution from 1 source ([30]).

- The requirement 8°@90% (Set B)

- is achieved with at least 20MHz in contribution from 1 source ([19])

- X = 20m in contribution from ([19])

- is NOT achieved with 40MHz in contribution from 1 source ([30]).

- NOTE: for each SL PRS bandwidth, the above observations are based on the best performance from each source.

- NOTE: for the relative positioning accuracy or distance accuracy of ranging, X is the maximum distance between UEs for performing relative positioning or ranging.

- NOTE: Super resolution is used by sources ([19], [24]), and is not used by source ([30]).

For Commercial use case, 5 sources ([19], [24], [25], [31], [32]) provided simulation results for FR1.

- For absolute horizontal positioning accuracy, the results were provided by 3 out of 5 sources.

- The requirement 1m@90%

- is achieved with 40MHz in contribution from 1 source ([19])

- and is achieved with at least 100MHz in contribution from 2 sources ([24], [30]).

- For Relative horizontal accuracy, the results were provided by 1 out of 5 sources.

- The requirement 1m@90%

- is achieved with 40MHz bandwidth in contribution from 1 source ([19]), where anchor UE deployment is additionally used for performing distance ranging

- and is achieved with 100MHz bandwidth in contribution from 1 source ([19])

- X = 10m in contribution from ([19]).

- For distance accuracy of ranging, the results were provided by 4 out of 5 sources. All 4 sources show that the target requirement set can be achievable by 100MHz especially for the cases with smaller X values.

- The requirement 1m@90%

- is achieved with at least 20MHz in contribution from 1 source ([25])

- X = 10m in contribution from ([25])

- is achieved with at least 40MHz in contribution from 2 sources ([19], [25])

- X = 10m in contribution from ([19]) where anchor UE deployment is additionally used for performing ranging

- X = 20m and 50m in contribution from ([25])

- is achieved with at least 100MHz in contribution from 3 sources ([19], [24], [31])

- X = 10m in contributions from ([19], [24], [31])

- and is NOT achieved with at least 100MHz in contribution from 2 sources ([24], [31])

- X = 20m, 50m, and 100m in contribution from ([24])

- X = 25m and 50m in contribution from ([31]).

- For angle accuracy of ranging, the results were provided by 1 out of 5 sources.

- The requirement 15°@90% (Set A)

- is achieved with at least 20MHz in contribution from 1 source ([19])

- X = 10m in contribution from ([19]).

- The requirement 8°@90% (Set B)

- is achieved with at least 40MHz in contribution from 1 source ([19])

- X = 10m in contribution from ([19]).

- NOTE: for each SL PRS bandwidth, the above observations are based on the best performance from each source.

- NOTE: for the relative positioning accuracy or distance accuracy of ranging, X is the maximum distance between UEs for performing relative positioning or ranging.

- NOTE: Super resolution is used by sources ([19], [24], [25], [31]), and is not used by source ([30]).

For IIOT use case in InF-SH scenario, 9 sources ([18], [19], [20], [21], [22], [24], [28], [31], [32]) provided simulation results for FR1, and 1 source ([32]) provided simulation results for FR2.

- For absolute horizontal poisoning accuracy, the results were provided by 8 out of 9 sources. 5 out of 8 sources show that the target requirements Set A can be achieved with at least 100MHz, and 5 out of 8 sources show that the target requirements Set B cannot be achieved with 100MHz.

- The requirement 1m@90% (Set A)

- is achieved with 20MHz in contributions from 1 source ([19])

- where Joint Uu/SL positioning is used in contribution from ([19])

- is achieved with 40MHz in contributions from 2 sources ([19], [20])

- where SL-only positioning is used in contribution from ([19])

- is achieved with at least 100MHz in contributions from 5 sources ([18], [21], [24], [28], [32])

- where LOS-only links are used in contribution from ([32])

- and is not achieved with 100MHz bandwidth in contribution from 1 source ([31]).

- The requirement 0.2m@90% (Set B)

- is achieved with at least 40MHz in contribution from 1 source ([19])

- where Joint Uu/SL positioning is used in contribution from ([19])

- and is achieved with at least 100MHz in contribution from 2 sources ([19], [20])

- where SL-only positioning is used in contribution from ([19])

- and is NOT achieved with 100MHz bandwidth in contributions from 6 sources ([18], [21], [24], [28], ([31]), [32])

- and is achieved with at least 200MHz bandwidth in FR2 in contribution from 1 source ([32])

- where LOS-only links are used in contribution from ([32]).

- For absolute vertical accuracy, the results were provided by 1 out of 9 sources.

- The requirement 1m@90% (Set A)

- is NOT achieved with 100MHz bandwidth in contribution from 1 source ([28]).

- The requirement 0.2m@90% (Set B)

- is NOT achieved with 100MHz bandwidth in contribution from 1 source ([28]).

- For Relative horizontal accuracy, the results were provided by 3 out of 9 sources. The performance of relative horizontal accuracy is worse than that of distance accuracy of ranging mainly due to additional angle estimation error. All 3 sources show Set A can be met with 40MHz or 100MHz PRS bandwidth. All 3 sources show Set B cannot be met even with 100MHz.

- The requirement 1m@90% (Set A)

- is achieved with at least 40MHz in contributions from 2 sources ([20], [22])

- X = 10m in contributions from ([20], [22])

- is achieved with at least 100MHz in contribution from 1 source ([19])

- X = 10m in contribution from ([19]).

- The requirement 0.2m@90% (Set B)

- is NOT achieved with 100MHz bandwidth in contributions from 3 sources ([19], [20], [22]).

- For distance accuracy of ranging, the results were provided by 5 out of 9 sources. 4 out of 5 sources show that the target requirement Set A can be achievable by 100MHz, and 3 out of 5 sources show that the target requirement Set B cannot be achieved with 100MHz bandwidth.

- The requirement 1m@90% (Set A)

- is achieved with at least 20MHz in contribution from 1 source ([20])

- X = 10m in contribution from ([20])

- is achieved with at least 40MHz in contribution from 1 source ([22])

- X = 10m in contribution from ([22])

- is achieved with at least 100MHz in contribution from 2 sources ([21], [24])

- X = 50m, 100m and 150m in contribution from ([21])

- X = 10m, 20m, 30m and 50m in contribution from ([24])

- is NOT achieved with at least 100MHz in contribution from 1 source ([31])

- X = 10m, and 50m in contribution from ([31]).

- The requirement 0.2m@90% (Set B)

- is achieved with at least 100MHz in contribution from 2 sources ([20], [22])

- X = 10m in contributions from ([20], [22])

- and is NOT achieved with 100MHz bandwidth in contributions from 3 sources ([21], [24], [31]).

- For angle accuracy of ranging, the results were provided by 2 out of 9 sources.

- The requirement 15°@90% (Set A)

- is achieved with at least 20MHz in contribution from 1 source ([20])

- X = 10m in contribution from ([20])

- is achieved with at least 40MHz in contribution from 1 source ([22])

- X = 10m in contribution from ([22]).

- The requirement 8°@90% (Set B)

- is achieved with at least 20MHz in contribution from 1 source ([20])

- X = 10m in contribution from ([20])

- is achieved with at least 40MHz in contribution from 1 source ([22])

- X = 10m in contribution from ([22]).

- NOTE: for each SL PRS bandwidth, the above observations are based on the best performance from each source.

- NOTE: for the relative positioning accuracy or distance accuracy of ranging, X is the maximum distance between UEs for performing relative positioning or ranging.

- NOTE: Super resolution is used by sources ([19], [20], [22], [24], [31], [32]), and is not used by sources ([18], [21]).

For IIOT use case in InF-DH scenario, 7 sources ([18], [19], [20], [24], [28], [30], [32]) provide simulation results for FR1, and 1 source ([32]) provided simulation results for FR2.

- For absolute horizontal poisoning accuracy, the results were provided by 7 sources. 5 out of 7 sources show that the target requirements Set A can be achieved with 100MHz, and 5 out of 7 sources show that the target requirements Set B cannot be achieved with 100MHz.

- The requirement 1m@90% (Set A)

- is achieved with 20MHz in contribution from 1 source ([19])

- where Joint Uu/SL positioning is used in contribution from ([19])

- is achieved with 40MHz in contribution from 2 sources ([19], [20])

- where SL-only positioning is used in contribution from ([19]

- and is achieved with at least100MHz in contributions from 3 sources ([24], [30], [32])

- where LOS-only links are used in contribution from ([32])

- and is NOT achieved with 100MHz bandwidth in FR1 in contributions from 2 sources ([18], [28]).

- The requirement 0.2m@90% (Set B)

- is achieved with at least 100MHz in contribution from 2 sources ([19], [20])

- is NOT achieved with 100MHz bandwidth in FR1 in contributions from 6 sources ([18], [24], [28], [30], [32])

- and is achieved with at least 200MHz bandwidth in FR2 in contribution from 1 source ([32])

- where LOS-only links are used in contribution from ([32]).

- For absolute vertical accuracy, the results were provided by 1 out of 7 sources.

- The requirement 1m@90% (Set A)

- is NOT achieved with 100MHz bandwidth in contribution from 1 source ([28]).

- The requirement 0.2m@90% (Set B)

- is NOT achieved with 100MHz bandwidth in contribution from 1 source ([28]).

- For Relative horizontal accuracy, the results were provided by 2 out of 7 sources.

- The requirement 1m@90% (Set A)

- is achieved with at least 40MHz in contribution from 1 source ([20])

- X = 10m in contribution from ([20])

- is achieved with at least 100MHz in contribution from 1 source ([19])

- X = 10m in contribution from ([19]).

- The requirement 0.2m@90% (Set B) in InF-DH

- is NOT achieved with 100MHz bandwidth in contribution from 2 sources ([19], [20]).

- For distance accuracy of ranging, the results were provided by 2 out of 7 sources.

- The requirement 1m@90% (Set A)

- is achieved with at least 20MHz in contribution from 1 source ([20])

- X = 10m in contribution from ([20])

- is achieved with at least 100MHz in contribution from 1 source ([24])

- X = 10m in contribution from ([24])

- and is NOT achieved with at least 100MHz in contribution from 1 source ([24])

- X = 20m, 30m, and 50m in contribution from ([24]).

- The requirement 0.2m@90% (Set B)

- is achieved with at least 100MHz in contribution from 1 source ([20])

- X = 10m in contribution from ([20])

- and is NOT achieved with 100MHz bandwidth in contribution from 1 source ([24]).

- For angle accuracy of ranging, the results were provided by 1 out of 7 sources.

- The requirement 15°@90% (Set A)

- is achieved with at least 20MHz in contribution from 1 source ([20])

- X = 10m in contribution from ([20]).

- The requirement 8°@90% (Set B)

- is achieved with at least 40MHz in contribution from 1 source ([20])

- X = 10m in contribution from ([20]).

- NOTE: for each SL PRS bandwidth, the above observations are based on the best performance from each source.

- NOTE: for the relative positioning accuracy or distance accuracy of ranging, X is the maximum distance between UEs for performing relative positioning or ranging.

- NOTE: Super resolution is used by sources ([19], [20], [24], [32]), and is not used by sources ([18], [30]).

### 5.3.2 Evaluation of absolute positioning, relative positioning, and ranging methods

The performance analysis for Rel-18 SL positioning shows that different SL positioning methods can be used to determine absolute position of a target UE:

- Simulation results for SL positioning based on SL-TDOA were reported in contributions from 13 sources ([18], [21], [22], [23], [24], [26], [27], [28], [29], [30], [31], [32], [78]).

- Simulation results for SL positioning based on SL-RTT (multi-RTT) were reported in contributions from 6 sources ([19], [20], [27], [28], [29], [30]).

- Simulation results based on two anchors SL-AOA were provided in contribution from 1 source ([26]).

For absolute positioning, 5 sources ([19], [24], [30], [32], [33]) provide simulation results for Joint Uu-SL absolute positioning.

- For V2X use case, 4 sources ([19], [24], [32], [33]) show performance improvement of Joint Uu-SL absolute positioning compared to SL-only positioning.

- For V2X use case, 2 sources ([32], [33]) show performance improvement of Joint Uu-SL absolute positioning compared to Uu-only positioning.

- For IIOT use case, 3 sources ([19], [24], [32]) show performance improvement of Joint Uu-SL absolute positioning compared to SL-only positioning.

- For IIOT use case, 3 sources ([24], [30], [32]) show performance improvement of Joint Uu-SL absolute positioning compared to Uu-only positioning.

- For Public safety, 1 source ([24]) shows performance improvement of Joint Uu-SL absolute positioning compared to SL-only or Uu-only positioning.

- For commercial use case, 1 source ([24]) shows performance improvement of Joint Uu-SL absolute positioning compared to SL-only positioning.

- For commercial use case, 2 sources ([24], [30]) show performance improvement of Joint Uu-SL absolute positioning compared to Uu-only positioning.

The performance analysis for Rel-18 SL positioning shows that, SL positioning methods can be used for relative positioning/ ranging between UEs. For relative positioning/ ranging positioning accuracy,

- Simulation results based on SL-RTT and/or AOA were provided in contributions from 12 sources ([19], [20], [21], [22], [23], [24], [25], [26], [27], [30], [31], [33]).

- Results based SL-TDOA were provided in contribution from 1 source ([32]).

Simulation results in contributions from 9 sources ([19], [20], [22], [23], [24], [25], [26], [27], [31]) show that relative horizontal accuracy and/or distance accuracy of ranging performance improves with decreasing values of X, where X is the maximum distance between two UEs for performing relative positioning or ranging.

- In some simulation cases, for a certain SL PRS bandwidth, a target requirement may be achieved for a smaller value of X but may not be achieved for a larger value of X.

- In some simulation cases, a target requirement may be achieved using a smaller SL PRS bandwidth for a smaller value of X but may only be achieved using a larger SL PRS bandwidth for a larger value of X.

From the reported simulation results, it is observed that SL absolute positioning performance may be degraded due to uncertainty in the anchor UEs' location coordinates and synchronization error (for SL-TDOA) between anchor UEs.

## 5.4 Potential specification impact for sidelink positioning

The following summarizes the key areas of potential specification impact from RAN1's perspective that have been identified for the support of solutions for sidelink positioning:

- Specification changes to support the following two operation scenarios:

- Operation Scenario 1: PC5-only-based positioning.

- Operation Scenario 2: Combination of Uu- and PC5-based positioning.

- Specification changes to introduce:

- RTT-type solution(s) using SL, SL-AoA, SL-TDOA (where DL-TDOA-like operation and UL-TDOA-like operation are included).

- At least the following measurements: SL PRS based Rx-Tx measurement, SL PRS based RSTD measurement, SL PRS based RSRP measurement, SL PRS based RSRPP measurement, SL PRS based RTOA measurement, SL PRS based Azimuth of Arrival (AoA) and SL Zenith of Arrival (ZoA) measurement.

- A new sidelink reference signal (SL PRS), including details of sequence design, physical structure, resource mapping.

- Support of unicast, Groupcast (not including many to one) and Broadcast of SL PRS transmissions,

- Support of SCI to be used for reserving/indicating one or more SL PRS resources.

- SL PRS resource allocation Scheme 1 and Scheme 2, where Scheme 1 corresponds to a network-centric resource allocation, and Scheme 2 corresponds to UE autonomous SL PRS resource allocation, and potential mechanisms for SL PRS resource coordination.

- SL PRS transmission in dedicated resource pool or shared resource pool that may be shared with Rel-16/Rel-17/Rel-18 SL communication.

- Support of Open Loop Power Control (OLPC) for SL PRS transmissions.

- Details of sidelink positioning measurement reporting.

RAN2 identified that there is potential specification impact for sidelink positioning including:

- Introduction of a new protocol for sidelink positioning procedures between UEs, with where it is specified to be determined during normative work.

- The new protocol is a separate ASN.1 module from LPP (this does not necessarily imply whether it is included in TS 37.355 [16]).

- Options for signaling between LMF and UE will be downselected during normative work.

From the perspective of NG-RAN interface, the following have been identified to have potential specification impact for support of sidelink positioning:

- Support of sidelink positioning and ranging service authorizations signaling to NG-RAN as needed.

# 6 Positioning enhancements for improved integrity, accuracy, and power efficiency

## 6.1 Integrity for RAT-dependent positioning techniques

### 6.1.0 Study objectives

The following objectives of the study on solutions for integrity for RAT-dependent positioning techniques are listed in the SID [7]:

- Identification of the error sources.

- Study of methodologies, procedures, signaling, etc for determination of positioning integrity for both UE-based and UE-assisted positioning.

- Reuse of concepts and principles developed for RAT-Independent GNSS positioning integrity are to be prioritized, when possible.

### 6.1.1 Identification of error sources

Sources of error for RAT-dependent positioning techniques are studied for timing-based and angle-based positioning methods focussing on the origin of the error source, the model of the error source, criteria for consideration as an error source, and mapping between an error source and a positioning method (e.g., DL, UL, DL&UL positioning method).

UE-based/assisted DL positioning methods, UL and DL&UL positioning methods are considered in the study.

For timing-based positioning methods, the following error sources are studied:

- TRP/UE measurements errors (e.g., ToA, Rx-Tx timing difference)

- Error in assistance data (e.g., TRP location, Inter-TRP synchronization errors (e.g., RTD))

- TRP/UE Timing error

- Identification of error sources resulting from the multipath/NLoS channel/radio propagation environment, including multipath/NLoS channel itself as an error source, can be considered further during normative work.

For angle-based positioning methods, the following error sources are studied:

- TRP/UE measurements errors (e.g., AoA, RSRP, RSRPP)

- Error in assistance data (e.g., TRP location, TRP beam antenna information)

- Identification of error sources resulting from the multipath/NLoS channel/radio propagation environment, including multipath/NLoS channel itself as an error source, can be considered further during normative work.

For UE-based positioning integrity mode, whether boresight direction of DL PRS (***NR-DL-PRS-BeamInfo*** in TS 37.355 [16]) and/or beam information (***NR-TRP-BeamAntennaInfo*** in TS 37.355 [16]) of DL PRS can be error sources can be considered further during normative work, focusing at least on the following aspects:

- Granularity of boresight direction of DL-PRS and its influence on positioning integrity

- Feasibility and complexity of modelling

- Feasibility of obtaining quality/statistical parameters of beam information from the gNB

- Influence on measurement errors at the UE.

For DL AoD, whether DL PRS RSRP/RSRPP measurement can be an error source is studied, focusing at least on the following aspect:

- Impact of RSRP/RSRPP measurement on positioning accuracy.

For LMF-based positioning integrity mode, whether System Frame Number (SFN) initialization time is an independent error source for UL-TDOA or UE-assisted DL-TDOA is studied.

Table 6.1.1-1 presents the identified error sources for LMF-based and UE-based positioning integrity modes for different positioning methods.

Table 6.1.1-1: Error sources for LMF-based and UE-based positioning integrity modes

| Positioning Integrity Mode | DL TDOA | UL TDOA | Multi-RTT | UL AoA | DL AoD |
| --- | --- | --- | --- | --- | --- |
| LMF-based (as defined in Table 9.4.1.1.1 in TR 38.857 [2]) | - RSTD measurement  - TRP location  - Inter-TRP synchronization (can be caused in part by errors in SFN initialization time.) | - RTOA measurement  - TRP location  - Inter-TRP synchronization (can be caused in part by errors in SFN initialization time.) | - UE Rx-Tx time difference measurement  - gNB Rx-Tx time difference measurement  - TRP location | - Angle of arrival measurement  - TRP location  - ARP location (e.g., ***ARPLocationInformation*** in TS 38.455 [17]) | - TRP location  - DL-PRS RSRPP of the first path or RSRP |
| UE-based (as defined in Table 9.4.1.1.1 in TR 38.857 [2]) | - TRP location (e.g., ***NR-TRP-LocationInfo*** in TS 37.355 [16])  - Inter-TRP synchronization (e.g., ***NR-RTD-Info*** in TS 37.355 [16]) |  |  |  | - TRP location (e.g., ***NR-TRP-LocationInfo*** in TS 37.355 [16]) |

The distributions of RSTD, RTOA, and UE/gNB Rx-Tx time difference measurement errors are studied considering the following aspects:

- Whether TEG-related timing error is an independent error source from timing related measurement error (e.g., RTOA, RSTD, UE/gNB Rx-Tx time difference)

- Whether the measurement error is considered for each ToA or for the reported RSTD value

- Other Details (e.g., mean and standard deviation).

The distribution of angle of arrival measurement error is studied considering the following aspects:

- Whether the angle of arrival measurement error can be expressed as the error of the AoA/ZoA in LCS or GCS or the error of a defined function of AoA/ZoA in LCS

- Distribution of AoA measurement error for an NLOS/LOS link

- Other Details (e.g., mean, standard deviation).

The following alternatives for expression of angle of arrival measurement error for determination of positioning integrity for UL AoA are studied with the aim of eventual down-selection:

- Alt. 1: No conversion (e.g., the measurement error is expressed as error in AoA or ZoA in LCS/GCS)

- Alt. 2: Conversion function (defined as function of AoA/ZoA in LCS).

Table 6.1.1-2 presents the choices of statistical distributions of the errors for the identified error sources.

Table 6.1.1-2: Identified candidates for distributions to model the errors due to different error sources

| Error source | Candidate(s) for distribution for error source |
| --- | --- |
| Timing measurement errors (NOTE 1, 2, 3) | Gaussian distribution |
| Inter-TRP synchronization errors | - Uniform distribution (NOTE 4)  - Gaussian distribution |
| TRP location error (e.g., ***NR-TRP-LocationInfo*** in [16]) | - Uniform distribution (NOTE 5)  - Gaussian distribution |
| TRP location error (e.g., Geographical coordinates in [17]) | - Uniform distribution  - Gaussian distribution |
| ARP location error (e.g., ***ARPLocationInformation*** in [17]) | - Uniform distribution  - Gaussian distribution |
| NOTE 1: Timing measurement errors are applicable to RSTD, RTOA and UE/gNB Rx-Tx time difference measurements.  NOTE 2: It is assumed that the timing measurement error is associated with the first path.  NOTE 3: It is assumed that the timing measurement error contains TEG related TX/RX timing error if the TEG related information is provided  NOTE 4: This may already be consistent with the uncertainty related to ***NR-RTD-Info*** in [16].  NOTE 5: This may already be consistent with the uncertainty related to ***NR-TRP-LocationInfo*** in [16]. | |

### 6.1.2 Methodologies, procedures and signaling for determination of positioning integrity

6.1.2.1 Integrity principle of operation

Reuse the concepts and principles developed for RAT-Independent GNSS positioning integrity for RAT-Dependent positioning integrity.

Both UE-based and LMF-based integrity for RAT-dependent cases are studied and supported in integrity for RAT-dependent positioning.

Use DNU flag for RAT-dependent integrity, with the meaning that the concerned assistance data cannot be used for integrity calculation but may be usable for positioning. Signaling details and relation to error sources can be determined in normative work.

6.1.2.2 Signaling for UE-based positioning integrity

Rel-17 UE-based integrity mode signaling can be used as baseline at least with the following aspects:

UE sends capability info to LMF on integrity for UE-based mode using LPP capability transfer procedure.

- LMF sends the assistance data for integrity calculation to UE. LMF provides, in assistance data, the information of error sources (e.g., originated from RAN node) to UE for integrity in UE-based mode.

- LMF sends integrity requirement e.g., TIR to UE in LPP request location information message for integrity of UE-based mode.

- UE sends integrity result to LMF using LPP location information Transfer message.

6.1.2.3 Signaling for LMF-based positioning integrity

RAN2 studied LMF-based positioning integrity mode [2], and have identified the following impacts to signaling:

- UE sends capability info to LMF for LMF-based positioning integrity mode using LPP capability transfer procedure

- LMF sends the request of results related to integrity for integrity error sources to UE for integrity of LMF-based mode

- LMF sends the request of results related to integrity for integrity error sources to RAN for integrity of LMF-based mode

- RAN sends results related to integrity to LMF using NRPPa message.

NOTE 1: The signaling to transmit integrity KPI and integrity results can be discussed during normative work.

NOTE 2: Whether UE sends results related to integrity to LMF using LPP message or not can be discussed during normative work.

### 6.1.3 Summary of evaluation results for integrity for RAT-dependent positioning techniques

The distribution of timing measurement error has been studied with evaluations reported by the following sources: [133], [135], [136], [137], [138], [139], [141], and [142].

The distribution of angle measurement error has been studied with evaluations reported by the following sources: [133], [134], [135], [137], [138], and [142].

Further details on the above can be found in Annex B.2.

### 6.1.4 Potential specification impact for integrity for RAT-dependent positioning techniques

For UE-based positioning integrity mode, potential specification impacts related to errors in assistance data (e.g., related to inter-TRP synchronization error and TRP locations) include at least the enhancements to assistance data from the LMF to the UE (e.g., inclusion of parameters related to the error sources).

Signaling design of both UE-based and LMF-based integrity can be supported.

## 6.2 PRS / SRS bandwidth aggregation

### 6.2.0 Study objectives

In the SID [7], the following is identified as an objective for the study of PRS/SRS bandwidth aggregation towards enabling higher accuracy positioning:

- Study solutions for accuracy improvement based on PRS/SRS bandwidth aggregation for intra-band carriers considering e.g., timing errors, phase coherency, frequency errors, power imbalance, etc.

### 6.2.1 Potential solutions based on PRS / SRS bandwidth aggregation

6.2.1.1 RF aspects

RF aspects of PRS/SRS bandwidth aggregation for intra-band contiguous carriers is studied by RAN4. Based on the study, PRS/SRS bandwidth aggregation for intra-band contiguous carriers is concluded as feasible for single chain Tx/Rx architectures at both the UE and gNB.

The assumption for a single-chain Tx architecture is that PRS/SRS resources to be aggregated are transmitted from a single Tx antenna.

6.2.1.2 RRM aspects

From the perspective of Radio Resource Management (RRM), the following are assumed for PRS bandwidth aggregation:

- A common numerology is required across all intra-band contiguous PFLs to be aggregated.

- PRS resources to be aggregated from different PFLs can have different bandwidths (i.e., different number of PRS RBs).

- PRS resources to be aggregated from different PFLs are transmitted in the same slot and in the same symbols.

- PRS resources to be aggregated from different PFLs are transmitted by the same TRP and associated with a common Antenna Reference Point (ARP).

From RRM perspective, the following are assumed for SRS bandwidth aggregation:

- A common numerology is required across all intra-band contiguous carriers to be aggregated.

- SRS resources to be aggregated from different carriers can have different bandwidths (i.e., different number of SRS RBs).

- SRS resources to be aggregated from different carriers are transmitted in the same slot and in the same symbols.

From RRM perspective, FFT/IFFT size is up to UE implementation. PRS/SRS bandwidth aggregation should allow UE implementation flexibility i.e., single FFT/IFFT or multiple FFTs/IFFTs (i.e., FFT/IFFT per carrier) implementations.

PRS/SRS bandwidth aggregation may be supported in RRC\_CONNECTED and RRC\_INACTIVE subject to UE capability.

PRS/SRS bandwidth aggregation across Positioning Frequency Layers (PFLs) for positioning measurements is concluded as feasible from RRM perspective.

### 6.2.2 Summary of evaluations for PRS/SRS bandwidth aggregation

RRM impact of possible group delay error between PRS/SRS from different carriers in single RF chain (Tx/Rx) architecture will be considered in RRM requirements during the WI.

### 6.2.3 Potential specification impact for PRS/SRS bandwidth aggregation

Specification of RRM requirements including at least PRS measurement period/reporting/accuracy (including margins), and the impacts of PRS measurement on data communication including CA/DC.

## 6.3 NR carrier phase positioning

### 6.3.0 Study objectives

In the SID [7], the following objectives for the study on solutions for accuracy improvement based on NR carrier phase measurements have been identified:

- Study on reference signals, physical layer measurements, and physical layer procedures to enable positioning based on NR carrier phase measurements for both UE-based and UE-assisted positioning.

In this study, the reuse of existing PRS and SRS is prioritized, with consideration of new reference signals only if found necessary.

In the following three clauses, potential solutions, achievable performance, and expected specification impact for support of positioning methods utilizing NR carrier phase measurements are presented.

For the purposes of discussion, for NR downlink and/or uplink carrier phase positioning, the carrier phase (CP) at a RF frequency at a receiver is a phase that is a function of the signal propagation time from a transmitter antenna reference point of a transmitter (e.g., a TRP or a UE) to a receiver antenna reference point of the receiver (e.g., a UE or a TRP). The propagation time can be expressed in a fractional part of a cycle of the RF frequency and a number of integer cycles, but the CP may be independent of the number of integer cycles.

### 6.3.1 Potential solutions for NR carrier phase positioning

#### 6.3.1.1 Reference signals for NR carrier phase positioning

Existing DL PRS and UL SRS for positioning can be re-used as the reference signals to enable positioning based on NR carrier phase measurements for both UE-based and UE-assisted positioning. Whether to consider enhancements of the existing DL PRS and UL SRS for better positioning performance can be considered further. Note that the use of MIMO SRS for positioning purpose is transparent to UE.

#### 6.3.1.2 Physical layer measurements for NR carrier phase positioning

The study of the accuracy improvement based on NR carrier phase measurements includes:

- UE-based and UE-assisted carrier phase positioning

- UL carrier phase positioning and DL carrier phase positioning

- NR carrier phase positioning with the carrier phase measurements of one carrier frequency or multiple frequencies

- Combination of NR carrier phase positioning with another standardized Rel. 17 positioning method, e.g., DL-TDOA, UL-TDOA, Multi-RTT, etc.

For DL UE-assisted NR carrier phase positioning, at least the following options are considered:

- The difference between the carrier phase measured from the DL PRS signal(s) of the target TRP and the carrier phase measured from the DL PRS signal(s) of the reference TRP

- The carrier phase measured from the DL PRS signal(s) of a TRP.

For UL UE-assisted NR carrier phase positioning, at least the carrier phase measured from the UL SRS for positioning purpose is considered.

#### 6.3.1.3 Physical layer procedures for NR carrier phase positioning

The impact of integer ambiguity on NR carrier phase positioning and potential solutions to resolve the integer ambiguity when using carrier phase measurements to estimate the propagation delay/distance between transmitting and receiving nodes are studied.

Benefits of using the carrier phase measurements of multiple DL PFLs for NR carrier phase positioning, which may include the impact of the time gap between the carrier phase measurements of multiple DL PFLs are studied.

NOTE 1: The initial phase error and the frequency error for each PFL can be modelled independently.

NOTE 2: For evaluations, the PRSs of all the PFLs of a TRP can be assumed to be transmitted from the same ARP or from different ARPs of the TRP.

NOTE 3: The location error for ARPs can be modelled independently.

NOTE 4: The timing errors of the PFLs may not be the same for PFLs in different bands or frequency ranges.

NOTE 5: In Rel-17, simultaneous reception of DL PRS from multiple frequency layers is not supported.

The impact of multipath/NLOS on NR carrier phase positioning is evaluated during the study item. Based on the study, it is concluded that multipath/NLOS deteriorates the performance of carrier phase positioning, and it is necessary to consider multipath mitigation for NR carrier phase positioning.

The effectiveness of the following multipath mitigation methods for NR carrier phase positioning is studied:

- Identification and separation of the first path and other paths.

- Reporting of the carrier phase of the first path, and optionally, the additional paths.

- The use of LOS/NLOS indication for the carrier phase measurements.

- NOTE: Rel-17 LOS/NLOS indicator can be considered as a starting point.

- The report of other channel information, such as existing RSRP/RSRPP.

The use of Positioning Reference Unit (PRU) to facilitate NR carrier phase positioning is studied.

- For DL NR carrier phase positioning, a PRU works as a UE to receive the DL PRS reference signals and provide the DL carrier phase measurements to the LMF, where the double differential measurements can be obtained by the difference of the DL carrier phase measurements from the target UE and those from the PRU for eliminating the measurement errors.

- For UL NR carrier phase positioning, a PRU works as a UE to transmit the UL SRS signals for positioning purpose. The TRPs provide the UL carrier phase measurements obtained from the UL SRS signals of the target UE and of the PRU to the LMF, where the double differential measurements can be obtained by the difference of these UL carrier phase measurements for eliminating the measurement errors.

The following approaches for NR carrier phase positioning are studied:

- The reporting of the carrier phase measurements together with the existing positioning measurements.

- The reporting of the carrier phase-based measurements alone without reporting the existing positioning measurements.

Potential solutions for NR carrier phase positioning are evaluated with the consideration of various error sources, which include phase noise (FR2), carrier frequency offset (CFO)/Doppler, oscillator-drift, transmitter/receiver antenna reference point (ARP) location errors, transmitter/receiver initial phase error, antenna Phase Center Offset (PCO) etc. Detailed evaluation methodology and assumptions are presented in Annex A.3

A summary of the evaluation results for the impact of the multipath/NLOS on NR carrier phase positioning are presented in Clause 6.3.2.

NR carrier phase positioning performance is evaluated at least with the carrier phase measurements of a single measurement instance.

It should be noted that the use of "carrier phase positioning" does not necessarily imply that it may be defined as a standalone positioning method.

The potential solutions of integer ambiguity resolution for NR carrier phase positioning were investigated in the study item, which include the following:

- Reporting of the carrier phases of more than one frequency from UE/TRP to LMF

- NOTE: frequency refers to frequency of carrier or frequency of subcarrier(s)

- Reporting of the determined integer ambiguity and/or the search range of the integer ambiguity from UE/TRP to LMF

- Reporting of the carrier phase measurements together with the legacy positioning measurements from UE/TRP to LMF

- Reporting of the new measurements from UE /TRP to LMF, e.g., based on carrier phase differentials across multiple subcarriers within a carrier

- NOTE: carrier phase differentials across multiple subcarriers within a carrier can be equivalent to time of arrival

- LMF configure the integer ambiguity range between the TRP and target UE (for UE-based NR CPP).

### 6.3.2 Summary of evaluations for NR carrier phase positioning

The methodology for the evaluation of NR carrier phase positioning can be found in Annex A.3.

Evaluations of NR carrier phase positioning were conducted using evaluation assumptions with some differences across sources. Different algorithms and methods are also used for estimating the carrier phases and determining UE's location based on the carrier phases. Thus, for the observations of evaluation results presented in this clause, it is important to consider the details of the evaluation assumptions as well as the algorithms and methods provided by each source in the references (e.g., in Annex B.4).

The accuracy of NR carrier phase positioning is evaluated under different scenarios (e.g., InF-SH, InF-DH) defined in [11] without considering the error sources listed in Annex A.3 (e.g., timing/ frequency errors, antenna PCO and ARP position errors). The evaluation results can be seen as the reference for studying the impacts of the error sources listed in Annex A.3. 9 out of 11 sources ([79], [80], [81], [82], [85], [86], [87], [88], [90]) show that the centimeter-level positioning accuracy can be achieved by the use of carrier phase measurements at least when other error sources are not considered. 2 out of 11 sources ([83], [84]) show that the centimeter-level positioning accuracy can be achieved by the use of ideal resolution of integer ambiguity:

- Source [79] shows:

- For InF-SH scenario:

- (No differential) UL-CPP (Case 1): <1.0cm @50% and <1.0cm @80%.

- SD UL-CPP (Case 5): <1.0cm @50% and <1.0cm @80%.

- DD DL-CPP (Case 9): <1.0cm @50% and <1.0cm @80%.

- For InF-DH scenario

- (No differential) UL-CPP (Case 2): <1.0cm @50% and <1.0cm @80%.

- SD UL-CPP (Case 6): <1.0cm @50% and 0.974m @80%.

- DD DL-CPP (Case 10): <1.0cm @50% and 1.014m @80%.

- Source [80] shows:

- For InF-SH scenario:

- SD DL-CPP (Case 102): <1.0cm@50% and <1.0cm @80%

- For InF-DH scenario

- SD DL-CPP (Case 202): <1.0cm@50% and 0.33m @80%

- Source [81] shows:

- For InF-SH scenario:

- SD DL-CPP (Case 2): <1.0cm @50% and <1.0cm @80%.

- DD DL-CPP (Case 3): <1.0cm @50% and <1.0cm @80%.

- DD DL-CPP (two subcarrier frequencies in one PFL) (Case 4): <1.0cm @50% and <1.0cm @80%.

- DD DL-CPP (two carrier frequencies, two PFLs) (Case 5): <1.0cm @50% and <1.0cm @80%.

- For InF-DH scenario

- SD DL-CPP (Case 7): 0.6cm @50% and 3.0cm @80%.

- DD DL-CPP (Case 8): 4.6cm @50% and 14.8cm @80%.

- DD DL-CPP (two carrier frequencies, two PFLs) (Case 9): 1.0cm @50% and 2.7cm @80%.

- Source [82] shows:

- For InF-SH scenario:

- DD DL-CPP (Case 1): <1cm @50% and <1cm @80%.

- Source [83] shows:

- For InF-SH scenario:

- SD DL-CPP (Case 1): <1cm @50% and <1cm @80% (with ideal resolution of integer ambiguity)

- Source [84] shows:

- For InF-SH scenario:

- SD DL-CPP (Case 1): <1cm @50% and <1cm @80% (with ideal resolution of integer ambiguity)

- Source [85] shows:

- For InF-SH scenario:

- DL-CPP (multiple subcarriers within one PFL) (Case 4-1-1): 0.11m @ 50% and 0.51m @80%

- DL-CPP (Case 4-1-2): 0.3cm @ 50% and 0.21m @ 80%

- For InF-DH scenario:

- DL-CPP (Case 4-2-1):0.33m @50% and 0.66m @ 80%.

- Source [86] shows:

- For InF-SH scenario (100MHz and 50MHz Bandwidth):

- SD DL-CPP (horizontal): <1cm @50% and <1cm @80%

- SD DL-CPP (vertical): <1cm @50% and <1cm @80%

- Source [88] shows:

- For InF-SH scenario (400MHz, FR2)

- SD DL-CPP (Case 1): 0.002cm @50% and <0.005cm @80%

- Source [87] shows:

- For InF-SH scenario (10MHz, @3GHz)

- Round-trip carrier phase with slope: < 1cm @ 50% and <1 cm @ 80%

- For InF-SH scenario (100MHz, @3.5GHz)

- Time domain and perfect phase: < 1cm @ 50% and <1 cm @ 80%

- Time domain and estimated phase: < 1cm @ 50% and ~1 cm @ 80%

- Source [90] shows:

- For InF-SH scenario

- DD UL-CPP: <1cm @50% and 2cm @80%

- NOTE 1: Unless indicated otherwise, the results shown above are for horizontal positioning accuracy with a single carrier of bandwidth of 100MHz in FR1.

- NOTE 2: Evaluation results above are mainly used as examples. Additional results and more details of the evaluation assumptions are provided in Annex B.4.

- NOTE 3: The evaluation results for legacy positioning approach may also be available in each of the sources, or in [2].

The impact of the initial phases of the transmitter and the receiver on NR carrier phase positioning (CPP) is evaluated in the study item. The evaluation results from the sources (e.g., [73], [74], [75], [76], [82]) show that if the impact of the initial phases of the transmitter and the receiver are not mitigated, it is impossible to support centimeter-level positioning accuracy.

The effectiveness of using Double Differential (DD) technique with PRU to eliminate the impact of the initial phases of the transmitter and the receiver on NR carrier phase positioning are evaluated in the study item. The evaluation results from the sources ([73], [77], [81], [82], [85]) show that the initial phases of the transmitter and the receiver can be removed effectively by the double differential technique with the use of PRU:

- Source [73] shows the positioning accuracy of <1cm (80%) for InF-SH and < 1cm (50%) for InF-DH can be reached when the PRU is located within a distance of 5m from the target UE.

- Source [81] shows the positioning accuracy of <1cm (80%) for InF-SH and 4.6cm (50%) for InF-DH can be reached under the condition that the PRU is located at a fixed location in LOS of the TRP.

- Source [77] shows that the accuracy of <1cm (50%) when the PRU is located within 1m of the target UE. However, the effectiveness reduces when the PRU is located away from the target UE because the channel conditions of the PRU is different from the target UE.

- Source [82] shows the positioning accuracy of < 1cm (80%) for InF-SH can be reached under the condition that the PRU is located a fixed location as shown in [82].

- Source [85] shows the positioning accuracy of < 1cm (50%) for InF-SH can be reached under the condition that the integer ambiguity range N is limited to ±1.

- Source [89] shows the distance accuracy degrades from 0.5cm @ 50% and 5.2cm @80% to 3.3cm @50% and 4.8cm @ 80% by the initial phase offset for InF-DH scenario.

NOTE 1: In the above results, all other error sources (except initial phase error) were not modelled.

NOTE 2: Unless indicated otherwise, the results shown above are for horizontal positioning accuracy with a single carrier of bandwidth of 100MHz in FR1.

NOTE 3. Evaluation results above are mainly used as examples. Additional results and more details of the evaluation assumptions are provided in Annex B.4.

The impact of the residual CFO at the transmitter and the receiver for NR carrier phase positioning are evaluated during the study item.

- The evaluation results from the sources ([73], [76]) show that the impact of residual CFO on carrier phase positioning is negligible.

- The evaluation results from the source ([75]) show that the impact of the residual CFO on the performance of carrier phase positioning can be mitigated with the use of the double differential technique with a PRU that is located at a fixed location in LOS of the TRP.

- The evaluation results from the source [80] show that the impact of residual CFO on carrier phase measurement is negligible. However, carrier phase positioning accuracy degrades significantly with residual CFO with single differential (SD) DL-CPP:

- With UE residual CFO 30Hz and TRP residual CFO 10Hz, the accuracy drops from 0.0044m to 0.2m @80% and from 0.0014m to 0.0017m @50% in InF-SH.

- With UE residual CFO 100Hz and TRP residual CFO 10Hz, the accuracy drops from 0.0044m to 0.27m @80% and from 0.0014m to 0.0024m @50% in InF-SH.

- The evaluation results from the source [86] show that carrier phase positioning accuracy degrades slightly with residual CFO with DD DL-CPP:

- With maximum residual CFO 30Hz between UE and TRP, the accuracy drops from 0.0010m to 0.0018m @50% and from 0.0046m to 0.0208m @80% in InF-SH.

- With maximum residual CFO 100Hz between UE and TRP, the accuracy drops from 0.0010m to 0.0027m @50% and from 0.0046m to 0.0440m @80% in InF-SH.

- The evaluation results from the source [88] show the impact of Doppler in FR1 at 3kmph is small enough that it has negligible impact on the carrier phase positioning accuracy with DD DL-CPP, in the simulated scenario under the agreed modelling for residual CFO.

NOTE 1: Unless indicated otherwise, the results shown above are for horizontal positioning accuracy with a single carrier of bandwidth of 100MHz in FR1.

NOTE 2: Evaluation results above are mainly used as examples. Additional results and more details of the evaluation assumptions are provided in Annex B.4.

The impact of the ARP errors on NR carrier phase positioning is evaluated. 8 out of 8 sources ([79], [80], [81], [85], [ 86], [87], [88], [90]) show that the ARP errors may have significant impact on NR carrier phase positioning accuracy. 3 out of 8 sources ([79], [81], [85]) show the impact of gNB ARP position errors on multi-frequency carrier phase positioning is much smaller than the impact on single-frequency carrier phase positioning.

- Source [79] shows:

- When double differential is not used:

- For InF-SH scenario with 1cm ARP error:

- UL-CPP (Case 23): 1.3368m @50% and 2.121m @80%

- For InF-DH scenario with 1cm ARP error:

- UL-CPP (Case 24): 1.2329m @ 50% and 1.9317m @80%

- When double differential is used:

- For InF-SH scenario with 1cm ARP error:

- (PRU 5m) DD UL-CPP (Case 27): <1cm @ 50% and 0.57269m @80%

- (PRU 2m) DD UL-CPP (Case31): <1cm @ 50% and <1cm @80%

- For InF-DH scenario with 1cm ARP error:

- (PRU 5m) DD UL-CPP (Case 28): 0.75118m @ 50% and 1.3217m @80%

- (PRU 2m) DD UL-CPP (Case 32): 0.56419m@ 50% and 1.1915m @80%

- When multi-frequ1ency carrier phase positioning is used:

- For InF-SH scenario with 1cm ARP error and random initial phase:

- (PRU 5m) DD UL-CPP (Case 47): 1.252cm @ 50% and 2.765cm @80%

- For InF-SH scenario with 5cm ARP error and random initial phase:

- (PRU 5m) DD UL-CPP (Case 48): 5.986cm @ 50% and 0.11879m @80%

- Source [80] shows:

- For InF-SH scenario with 1cm ARP error:

- SD DL-CPP: 0.09m @50% and 0.20m @80%.

- For InF-SH scenario with 5cm ARP error:

- SD DL-CPP: 0.18m @50%and 0.28m @80%

- Source [81] shows:

- For InF-SH scenario with 1cm ARP error:

- DD DL-CPP (Cases 11): <1.0cm @50% and 11.2cm @80%.

- DD DL-CPP (two subcarrier frequencies within one PFL) (Case 12): <1.0cm @50% and 1.79 cm @80%.

- DD DL-CPP (two carrier frequencies) (Case 13): <1.0cm @50% and 1.3cm @80%.

- For InF-SH scenario with 5cm ARP error:

- DD DL-CPP (two carrier frequencies, two PFLs) (Case 15): 3.3cm @50% and 5.6cm @80%.

- For InF-DH scenario with 1cm ARP error:

- DD DL-CPP (two carrier frequencies, two PFLs) (Case 17): 1.5cm @50% and 3.3cm @80%.

- Source [85] shows:

- For InF-SH scenario with 1cm ARP error:

- DL-CPP (single carrier, case 3-2-1): 0.24m@50% and 0.44m@80%.

- DL-CPP (multiple subcarriers within one PFL, case 3-2-4): 0.12m @50% and 0.25m@80%

- For InF-SH scenario with 5cm ARP error:

- DL-CPP (single carrier, case 3-2-3): 0.28m@50% and 0.44m@80%

- DL-CPP (multiple subcarriers within one PFL, case 3-2-6): 0.15m@50% and 0.30m@80%

- Source [86] shows:

- For InF-SH scenario with 1cm ARP error:

- DD DL-CPP (single carrier): 0.188m (50%), 0.386m (80%)

- Source [87] shows:

- For InF-SH scenario with 2cm ARP error and random initial phase

- DL-CPP (single carrier, case 08): 1.06m @50% and 1.54m @80%

- Source [88] shows:

- For InF-SH scenario with 1cm ARP error

- DD DL-CPP(Case 6, FR2): 3.487cm (50%) and 7.907cm (80%) (PRU-UE range R = 1m)

- DD DL-CPP(Case 14, FR1): 0.05m (50%) and 0.18m (80%)

- Source [90] shows:

- For InF-SH scenario with 1cm ARP error (average PRU-UE distance = 1m)

- DD DL-CPP: 1.5cm (50%) and 3.0cm (80%)

- For InF-SH scenario with 5cm ARP error (average PRU-UE distance = 1m)

- DD DL-CPP: 10cm (50%) and 0.44m (80%)

NOTE 1: Unless indicated otherwise, the results shown above are for horizontal positioning accuracy with a single carrier of bandwidth of 100MHz in FR1.

NOTE 2. Evaluation results above are mainly used as examples. Additional results and more details of the evaluation assumptions are provided in Annex B.4.

NOTE 3: The evaluation of multi-frequency carriers is based on the agreed assumption in Annex A.4 without requiring a UE to simultaneously measure more than one DL PFL.

The impact of the UE/TRP PCO errors on NR carrier phase positioning is evaluated in the study item. 2 out of 4 sources ([79], [80]) show that when UE/TRP antenna PCO model of Example 2 is used, the impact of the PCO errors can be significant. 2 out of 4 sources ([81], [88]) show that when UE/TRP antenna PCO model of Example 1 is used, the impact of the PCO errors can be negligible.

- Source [79] shows:

- For InF-SH scenario with a=3:

- SD DL-CPP (Case 37): 0.8469m @50% and 1.3922m @80%.

- DD DL-CPP (Case 41): < 1cm @50% and <1cm @80%.

- For InF-DH scenario with a=3:

- SD DL-CPP (Case 38): 0.9192m @50% and 1.4393m @80%.

- DD DL-CPP (Cases 42): 0.4896m @50% and 1.2148m @80%

- Source [80] shows:

- For InF-SH scenario with SD DL-CPP:

- PCO model (a=1, w=[-2, +2], dPhi= [0, 5]): <1cm @50% and 0.06m @80%

- PCO model (a=3, w=[-5, +5], dPhi= [0, 5]): <1cm @50% and 0.06m @80%

- PCO model (a=3, w=[-5, +5], dPhi= [0, 20]): 0.046m @50% and 0.19m @80%

- Source [81] shows:

- For InF-SH scenario:

- DD DL-CPP (Cases 20/21): < 1cm @50% and <1cm @80%.

- For InF-DH scenario:

- DD DL-CPP (Cases 22/23): <=1.3cm @50% and <=2.8cm @80%

- Source [88] shows:

- For InF-SH scenario:

- DD DL-CPP (Cases 4, FR2):

- PCO model (a=0, w=5: 0.014cm @50% and 0.063cm @80%

- PCO model (a=1, w=5: 0.015cm @50% and 0.076cm @80%

- PCO model (a=3, w=5: 0.014cm @50% and 0.270cm @80%

- DD DL-CPP (Cases 12, FR1):

- PCO model (a=1, X=5: 0.04m @50% and 0.08m @80%

- PCO model (a=3, X=5: 0.04m @50% and 0.08m @80%

NOTE 1: Unless indicated otherwise, the results shown above are for horizontal positioning accuracy with a single carrier of bandwidth of 100MHz in FR1.

NOTE 2: Evaluation results above are mainly used as examples. Additional results and more details of the evaluation assumptions are provided in Annex B.4.

The potential benefits of using the carrier phases of multiple carriers or multiple subcarriers are evaluated in the study item.

- The evaluation results from the sources (e.g., [79], [81], [85]) show that the use of the carrier phases of multiple carriers or multiple subcarriers together with double differential technique are beneficial for improving the accuracy of double differential carrier phase positioning.

- One source ([80]) show there is no benefit with the use of the carrier phases of multiple carriers for carrier phase positioning when single differential carrier phase positioning is used.

- The evaluation results from the source [87] show that the use of the carrier phases of multiple subcarriers together with round trip carrier phase technique is beneficial for improving the accuracy of carrier phase positioning.

- The evaluation from the sources [88]) show that combining carrier phase measurements from multiple groups of subcarriers is inferior to coherent processing of all subcarriers to obtain a single more accurate carrier phase measurement.

- The evaluation results from the source [89] shows the use of multiple subcarrier technique is beneficial over single carrier.

- Source [79] shows:

- When single-frequency carrier phases are used:

- For InF-SH scenario with 5cm ARP error and random initial phase:

- (PRU within 5m) DD UL-CPP (Case 45): 0.73594m @ 50% and 1.3812m @80%

- When multi-frequency carrier phases are used:

- For InF-SH scenario with 5cm ARP error and random initial phase:

- (PRU within 5m) DD UL-CPP (Case 48): 5.986cm @ 50% and 0.11879m @80%.

- Source [80] shows:

- When multi-frequency carrier phases are used:

- For InF-SH scenario without other errors,

- SD DL-CPP horizontal accuracy (Cases 703): < 1cm @50% and <1cm @80%.

- For InF-SH scenario with ARP error

- SD DL-CPP horizontal accuracy (Cases 703): < 1cm @50% and 0.18m @80%

- For InF-SH scenario with initial phase error

- SD DL-CPP horizontal accuracy (Cases 704): < 0.18m @50% and 0.34m @80%

- For InF-SH scenario with PCO

- SD DL-CPP horizontal accuracy (Cases 705): < 0.18m @50% and 0.13m @80%.

- Source [81]) shows:

- For InF-SH scenario with other errors (ARP error, random initial phase, CFO/ Oscillator-drift)

- DD DL-CPP horizontal accuracy (Cases 27/28): < 1cm @50% and <=2cm @80%.

- For InF-DH scenario:

- DD DL-CPP horizontal accuracy (Cases 29): 1.6cm @50% and 3.5cm @80%.

- Source [85] shows

- When multiple subcarriers with in one PFL are used:

- For InF-SH scenario with other errors (initial phase on both TRP and UE sides)

- DL-CPP accuracy (Case 1-2-9, N is limited to ±1): 0.12 m@50% and 0.25m @80%.

- Source [87] shows:

- For InF-SH scenario (10MHz, @3GHz)

- With multiple sub-carriers and round-trip carrier phase: < 1cm @ 50% and <1 cm @ 80%.

- Source [88] shows:

- For InF-SH scenario:

- DD DL-CPP horizontal accuracy (Case 8, FR2): 0.05526m @50% and 1.42119m @80%.

- Source [89]) shows:

- For InF-DH scenario:

- Distance accuracy (Case 3): 0.44cm @50% and 0.55cm @80%.

NOTE 1: Unless indicated otherwise, the results shown above are for horizontal positioning accuracy with a single carrier of bandwidth of 100MHz in FR1.

NOTE 2: Evaluation results above are mainly used as examples. Additional results and more details of the evaluation assumptions are provided in Annex B.4.

The effectiveness of using round-trip carrier phase technique to mitigate the impact of the initial phases of the transmitter and the receiver on NR carrier phase positioning is evaluated by source [87] for InF-SH, which shows achievability of horizontal positioning accuracy of:

- 0.5cm @80% with continuous sub-carrier allocation in 10 MHz BW (i.e., with enhanced PRS),

- 1cm @80% with Comb-4 sub-carrier allocation in 10 MHz BW and no sub-carrier offset change between symbols (i.e., with enhanced PRS), and

- 1.5cm @80% with Comb-4 sub-carrier allocation in 10 MHz BW and with sub-carrier offset change between symbols (i.e., with existing PRS).

NOTE: The evaluation results assumed phase coherency between the transmit path and the receive path of each device.

The positioning accuracy of Phase-Difference-based AoD positioning has been evaluated. Source in [88] shows that, for InF-SH with 20 MHz, a positioning accuracy of 1m (at 80%) is achievable.

### 6.3.3 Potential specification impact for NR carrier phase positioning

Regarding the reference signals for NR carrier phase positioning:

- Existing DL PRS and UL SRS for positioning purpose are recommended as the reference signals to enable positioning based on NR carrier phase measurements for both UE-based and UE-assisted positioning if NR CPP is introduced.

NOTE: The use of SRS MIMO for NR carrier phase positioning is transparent for UE.

Regarding the physical layer measurements for NR carrier phase positioning:

- New measurements are recommended to be introduced for supporting UE-based and UE-assisted NR carrier phase positioning, if NR CPP is introduced. The new measurements include, at least, the following:

- For DL carrier phase positioning, the following candidate measurements are identified (potential down-selection may be considered during normative work).

- The difference between the carrier phase measured from the DL PRS signal(s) of the target TRP and the carrier phase measured from the DL PRS signal(s) of the reference TRP;

- The carrier phase measured from the DL PRS signal(s) of a TRP.

- For UL carrier phase positioning, the carrier phases measured from the UL SRS for positioning purpose is identified as the UL carrier phase measurements.

NOTE: This proposal does not imply which carrier phase measurements are mapped to which positioning technique.

Multipath mitigation methods for the carrier phase positioning are recommended to be introduced during normative work, if NR CPP is introduced. The candidate solutions may include, but are not limited to, the following:

- Reporting of the carrier phase of the first path.

- At least reporting of the carrier phase of the first path, and optionally, the additional paths.

- The use of LOS/NLOS indication for the carrier phase measurements.

- NOTE: Rel-17 LOS/NLOS indicator can be considered as a starting point.

- Reporting of other channel information together with carrier phase measurements, such as existing RSRP/RSRPP.

At least the double differential technique with PRU is feasible for UE-based, and UE-assisted NR carrier phase positioning, if NR CPP is introduced, at least, for eliminating the impact of the initial phases of the transmitter and the receiver.

NOTE 1: How to efficiently enable the use of the PRU for supporting NR double differential carrier phase positioning needs further discussion during normative work.

NOTE 2: The required PRU density also needs further discussion during normative work.

NOTE 3: Other methods for eliminating the impact of the initial phases of the transmitter and the receiver are not precluded.

## 6.4 Low power high accuracy positioning

### 6.4.0 Study objectives

For the study on enhancing the power efficiency of RAT-dependent positioning methods for LPHAP use cases, the following objectives have been identified in the SID:

- Study of the requirements on LPHAP as developed by SA1 and evaluation of whether existing RAN functionality can support the power consumption and positioning requirements.

- Based on the evaluation, and, if found beneficial, study of potential enhancements to help address any limitations.

The study is limited to enhancements to RRC\_INACTIVE and/or RRC\_IDLE states.

### 6.4.1 Target use cases and requirements for low power high accuracy positioning

Use case 6 defined in TS 22.104 [6] is the single representative use case for the study of LPHAP.

For LPHAP, the main objective of the evaluations from the perspective of lower layers is on UE power consumption.

At least relative power unit is adopted as the performance metric to evaluate the power consumption of the Rel-17 RRC\_INACTIVE state positioning and potential enhancements.

A reference device (e.g., a mobile phone) with reference traffic type, reference battery capability, and reference battery life is defined for the purpose of identification of the performance gap that achieved by the Rel-17 RRC\_INACTIVE state positioning baseline and the target battery life of LPHAP use case 6.

For the service type, at least the 'Low Power Periodic and Triggered 5GC-MT-LR Procedures' in TS 23 .273 [144] is supported.

For the evaluations of LPHAP use case 6, the following performance requirements are considered:

- Horizontal positioning accuracy < 1 m for 90% of UEs

- Positioning interval / duty cycle of 15-30 s

- UE battery life of 6 months – 1 year.

### 6.4.2 Potential enhancements for low power high accuracy positioning

#### 6.4.2.1 Physical layer aspects

For UL and DL+UL positioning for UEs in RRC\_INACTIVE, the potential benefits and performance gains of enhancements on SRS for positioning to avoid frequent SRS (re)configurations are studied, including at least the following:

- The (pre-)configuration of SRS for positioning. Details, e.g., signaling and procedure, whether/how it is applicable to an area across multiple cells, consideration of UL overhead/capacity implied by (pre-)configuration and multiple cells, etc. can be considered further during normative work.

- SRS for positioning activation/request procedure(s), e.g., network activation of SRS via paging, UE request to obtain/update SRS via RACH-based procedure.

- Events of invalidity of SRS configuration to trigger the UE request procedure can be considered further during normative work.

- Whether the enhancements may be applicable to UEs in RRC\_IDLE state can be considered further during normative work.

From RAN1's perspective, DL PRS measurement for UEs in RRC\_IDLE state is recommended for the normative work.

Enhancements on simplified DL PRS configuration with 1-symbol PRS can be studied further and if needed, specified during normative phase.

#### 6.4.2.2 Higher layer aspects

The potential enhancements for Low Power High Accuracy Positioning in higher layer aspect are studied as below:

a. Enhancements on SRS configuration

Higher layer studied the following candidate enhancements on SRS configuration.

- Validity area mechanism

- SRS positioning validity area for UL positioning in RRC\_INACTIVE can avoid reconfiguration of SRS configuration upon cell reselection and is recommended for normative work from RAN2's perspective if feasible from RAN1's perspective.

- The solution should not require the gNB to monitor multiple SRS configuration simultaneously for a UE.

- SRS configuration request

SRS configuration request can be discussed during normative work from RAN2 perspective. Scenarios requiring SRS configuration request include:

- Scenario 1: During the UL positioning procedure, when the SRS configuration turns invalid, e.g., when the UE moves out of the SRS positioning validity area.

- Scenario 2: At the initiation of UL positioning procedure when an event is detected.

Detailed solution for the SRS update, e.g., with RRC message, UL MAC, or NG-AP message can be discussed in the WI phase.

- Pre-configure multiple SRS

Pre-configuration of multiple SRS configurations (e.g., for multiple SRS positioning validity areas) is feasible from RAN2 perspective and can be discussed in normative work.

The pre-configuration of multiple SRS configurations can be delivered to the UE either by dedicated signalling or SI broadcast.

b. Enhanced DL-PRS configuration

Alignment between DRX and PRS is beneficial from power saving point of view for LPHAP and is recommended to normative work. Two directions of solutions for DRX/PRS alignments are considered:

- PRS alignment with fixed DRX

- DRX alignment with fixed PRS

Solutions for the PRS/DRX alignment, e.g., LMF-based/UE-based solution, is to be discussed.

Impacts to different RRC states (RRC\_INACTIVE and RRC\_IDLE) is to be discussed.

c. Exposure of LPHAP information to the gNB and/or LMF

Exposure of LPHAP information to the gNB and/or LMF (e.g., as a UE capability) can be discussed in normative work if any enhancement for LPHAP is agreed, taking into account any guidance from SA2.

d. Positioning in RRC\_IDLE state

- DL positioning in RRC\_IDLE is recommended to normative work from RAN2's perspective if power saving benefits are confirmed by RAN1.

Measurement is performed in RRC\_IDLE while measurement report is sent in RRC\_CONNECTED.

Feasibility of measurement report in msg5 should be evaluated with SA2/3 involved.

Whether the CN can handle the measurement reports from the UE in RRC\_CONNECTED, while the positioning measurement was performed in RRC\_IDLE, can be evaluated in the WI phase with SA2 involved.

e. Paging relaxation

Paging relaxation by skipping paging reception in RRC\_INACTIVE for LPHAP is beneficial from power saving point of view and feasible from RAN2's perspective. Skipping paging reception in RRC\_INACTIVE is recommended for normative work from RAN2's perspective for achieving LPHAP requirements, if feasible and beneficial from RAN1's perspective.

The power saving gain can be further evaluated in RAN1. Impacts of skipping paging for UE in RRC\_INACTIVE to the core network could be evaluated with SA2 involved in the WI phase.

### 6.4.3 Summary of evaluations for low power high accuracy positioning

The methodology for the evaluation of Low Power High Accuracy Positioning (LPHAP) can be found in Annex A.4.

Evaluations of baseline Rel-17 RRC\_INACTIVE state positioning with the evaluation assumptions agreed for the study show that the power consumption on deep sleep state accounts for the highest proportion in the total power.

For the evaluation on the battery life of the baseline LPHAP Type A device with battery capacity C2 of 800mAh:

- Based on the results provided by all sources, the target requirement of 6~12 months is not achieved by the existing Rel-17 positioning for UEs in RRC\_INACTIVE state with baseline implementation factor K = 1 and baseline evaluation assumptions.

- Based on the results provided by all sources, the target requirement of 6~12 months is not achieved by the existing Rel-17 positioning for UEs in RRC\_INACTIVE state with optional implementation factor K or optional evaluation assumptions.

- For UE-assisted DL positioning, results are provided by 14 sources ([92], [36], [93], [97], [40], [102], [43], [98], [45], [48], [50], [52], [53], [99]) out of 20 sources, and the following are observed:

- The target requirement of 6 months is achieved by 0 source, and is not achieved by 14 sources ([92],[36],[93],[97],[40],[102],[43],[98],[45],[48],[50],[52],[53], [99]) even with the most power efficient case that I-DRX cycle of 10.24s, 1 RS per 1 I-DRX cycle, high SINR, CG-SDT for measurement reporting, and implementation factor K = 4.

- The target requirement of 12 months is achieved by 0 source, and is not achieved by 14 sources ([92],[36],[93],[97],[40],[102],[43],[98],[45],[48],[50],[52],[53], [99]) even with the most power efficient case that I-DRX cycle of 10.24s, 1 RS per 1 I-DRX cycle, high SINR, CG-SDT for measurement reporting, and implementation factor K = 4.

- For UE-based DL positioning, results are provided by 11 sources ([92], [36], [93], [97], [40], [43], [98], [45], [50], [52], [99]) out of 20 sources, and the following are observed:

- The target requirement of 6 months is achieved by 0 source, and is not achieved by 11 sources ([92],[36],[93],[97],[40],[43],[98],[45],[50],[52], [99]) even with the most power efficient case that I-DRX cycle of 10.24s, 1 RS per 1 I-DRX cycle, high SINR, and implementation factor K = 4.

- The target requirement of 12 months is achieved by 0 source, and is not achieved by 11 sources ([92],[36],[93],[97],[40],[43],[98],[45],[50],[52], [99]) even with the most power efficient case that I-DRX cycle of 10.24s, 1 RS per 1 I-DRX cycle, high SINR, and implementation factor K = 4.

- For UL positioning, results are provided by 13 sources ([92], [36], [93], [97], [40], [43], [98], [45], [48], [50], [52], [53], [99]) out of 20 sources, and the following are observed:

- The target requirement of 6 months is achieved by 0 source, and is not achieved by 13 sources ([92], [36], [93], [97], [40], [43], [98], [45], [48], [50], [52], [53], [99]) even with the most power efficient case that I-DRX cycle of 10.24s, 1 RS per 1 I-DRX cycle, high SINR, no SRS (re)configuration, and implementation factor K = 4.

- The target requirement of 12 months is achieved by 0 source, and is not achieved by 13 sources ([92], [36], [93], [97], [40], [43], [98], [45], [48], [50], [52], [53], [99]) even with the most power efficient case that I-DRX cycle of 10.24s, 1 RS per 1 I-DRX cycle, high SINR, no SRS (re)configuration, and implementation factor K = 4.

- For DL+UL positioning, results are provided by 1 source ([52]) out of 20 sources, and the following are observed:

- The target requirement of 6 months is achieved by 0 source and is not achieved by 1 source ([52]) even with the most power efficient case that I-DRX cycle of 10.24s, 1 RS per 1 I-DRX cycle, high SINR, no SRS (re)configuration, CG-SDT for measurement reporting, and implementation factor K = 4.

- The target requirement of 12 months is achieved by 0 source and is not achieved by 1 source ([52]) even with the most power efficient case that I-DRX cycle of 10.24s, 1 RS per 1 I-DRX cycle, high SINR, no SRS (re)configuration, CG-SDT for measurement reporting, and implementation factor K = 4.

For the evaluation on the battery life of the optional LPHAP Type B device with battery capacity C2 of 4500mAh:

- Based on the results provided by all sources, the target requirement of 6~12 months is not achieved by the existing Rel-17 positioning for UEs in RRC\_INACTIVE state with the baseline implementation factor K=1 and baseline evaluation assumptions.

- For UE-assisted DL positioning, results are provided by 9 sources ([36], [93], [97], [102], [43], [45], [50], [52], [98]) out of 20 sources, and the following are observed:

- The target requirement of 6 months is achieved by 5 sources ([36], [45], [52], [98], [102]) with the implementation factor K = 4 and by 4 sources ([43],[50], [93], [97]) with the implementation factor K >= 2, and is not achieved by 5 sources with the implementation factor K < 4 ([36], [42], [45], [52], [98]) and by 4 sources ([43],[50], [93], [97]) with the implementation factor K < 2.

- The target requirement of 12 months is achieved by 5 sources ([43], [50], [52], [93], [97]) with the case that I-DRX cycle of 10.24s, 1 RS per 1 I-DRX cycle, high SINR, CG-SDT for reporting and implementation factor K = 4, and is not achieved by 9 sources ([36], [93], [97], [102], [43], [45], [50], [52], [98]) with the implementation factor K < 4.

- For UE-based DL positioning, results are provided by 8 sources ([36], [93], [97], [43], [45], [50], [52], [98]) out of 20 sources, and the following are observed:

- The target requirement of 6 months is achieved by 4 sources ([36], [45], [52], [98]) with the implementation factor K = 4 and by 4 sources ([43], [50], [93], [97]) with the implementation factor K >= 2 , and is not achieved by 4 sources with the implementation factor K < 4 ([36], [45], [52], [98]) and by 4 sources ([43],[50], [93], [97]) with the implementation factor K < 2;

- The target requirement of 12 months is achieved by 5 sources ([43], [50], [52], [93], [97]) with the case that I-DRX cycle of 10.24s, 1 RS per 1 I-DRX cycle, high SINR, and implementation factor K = 4, and is not achieved by 8 sources ([36], [93], [97], [43], [45], [50], [52], [98]) with the implementation factor K < 4.

- For UL positioning, results are provided by 8 sources ([36], [93], [97], [43], [45], [50], [52], [98]) out of 20 sources, and the following are observed:

- The target requirement of 6 months is achieved by 4 sources ([36], [45], [52], [98]) with the implementation factor K = 4 and by 4 sources ([43],[50], [93], [97]) with the implementation factor K >= 2, and is not achieved by 4 sources ([36], [45], [52], [98]) with the implementation factor K < 4 and by 4 sources ([43], [50], [93], [97]) with the implementation factor K < 2;

- The target requirement of 12 months is achieved by 5 sources ([43], [50], [52], [93], [97]) with the case that I-DRX cycle of 10.24s, 1 RS per 1 I-DRX cycle, high SINR, no SRS (re)configuration, and implementation factor K = 4, and is not achieved by 8 sources ([36], [93], [97], [43], [45], [50], [52], [98]) with the implementation factor K < 4.

- For DL+UL positioning, results are provided by 1 source ([52]) out of 20 sources, and the following are observed:

- The target requirement of 6 months is achieved by 1 source ([52]) with implementation factor K = 4, and is not achieved by 1 source ([52]) with implementation factor K < 4;

- The target requirement of 12 months is achieved by 1 source ([52]) with the case that I-DRX cycle of 10.24s, 1 RS per 1 I-DRX cycle, high SINR, no SRS (re)configuration, CG-SDT for measurement reporting, and implementation factor K = 4, and is not achieved by 1 source ([52]) with implementation factor K < 4.

NOTE: The implementation factor K is a factor related to the reference device in the model to convert the relative power unit to the battery life. Four values are introduced for K with K = 1 as the baseline and K = 0.5, 2, 4 as optional values. The model is captured in the Annex A.4.

NOTE: Without otherwise noted, "high SINR" in the observation refers to the evaluation case that no intra-/inter-frequency RRM and single SSB for synchronization purpose is considered.

From evaluations for a LPHAP device, it is observed that the existing Rel-17 positioning procedures for UEs in RRC\_INACTIVE state cannot satisfy the target battery life required by LPHAP use case 6 for majority of the evaluation scenarios that are examined.

Based on the evaluations, it is concluded that enhancements to meet the target battery life in Rel-18 are necessary.

Evaluation results of extending DRX cycle are provided by 13 sources ([92], [93], [94], [96], [97], [98], [99], [101], [102], [103], [108], [109], [110]) out of 19 sources, the following is observed:

- Results with extended DRX cycle beyond 10.24s provide power saving gains with respect to that with the baseline DRX cycle of 1.28s and is beneficial towards meeting the battery life requirement as extended DRX cycle beyond 10.24s allows a UE to remain in a deeper sleep state for a longer duration.

- From the evaluations,

- Power saving gains achieved with extended DRX cycle with respect to baseline DRX cycle 1.28s are provided by 2 sources ([93], [103]):

- In [93], 87%~90% power saving gains are achieved with DRX cycle of 30.72s with respect to that with the baseline DRX cycle of 1.28s.

- In [103], 35.05%~53.70% power saving gains are achieved with DRX cycle of 10.24s with respect to that with the baseline DRX cycle of 1.28s, and 37.56%~57.53% power saving gains are achieved with DRX cycle of 20.48s with respect to that with the baseline DRX cycle of 1.28s.

- Results on battery life of extended DRX cycle together with ultra-deep sleep state are provided by 13 sources ([92], [93], [94], [96], [97], [98], [99], [101], [102], [103], [108], [109], [110]), and the target requirement of 6~12 months is achieved by 12 sources in some cases.

Evaluation results of UE (re)entering RRC\_CONNECTED state to obtain SRS (re)configuration for UL/DL+UL positioning are provided by 7 sources ([92], [93], [94], [99], [101], [103], [109], [110]) out of 19 sources, the following is observed:

- UE (re)entering RRC\_CONNECTED state to obtain SRS (re)configuration increases power consumption, and results without SRS (re)configuration procedure provide power saving gains with respect to that with (re)entering RRC\_CONNECTED state to obtain SRS (re)configuration.

- From the evaluations,

- In [92], 65.2790% of total power is consumed by SRS (re)configuration for UL positioning; UE (re)entering RRC\_CONNECTED state to obtain SRS (re)configuration increases the power consumption by 3 times.

- In [93], UE (re)entering RRC\_CONNECTED state to obtain SRS (re)configuration every 10.24s/20.48s/40.96s increases the power consumption by 8.71%/4.47%/2.23% with DRX cycle of 1.28s and by 13.38%/6.69%/3.34% with DRX cycle of 10.24s.

- In [94], 23.81%~52.62% of total power is consumed by SRS (re)configuration for UL positioning, and 21.65%~26.54% of total power is consumed by SRS (re)configuration for DL+UL positioning.

- In [101], 11.6%~34.4% of total power is consumed by SRS (re)configuration for UL positioning with ultra-deep sleep state option 1 with additional transition energy 10000, and 46.2%~77.5% of total power is consumed by SRS (re)configuration for UL positioning with ultra-deep sleep state option 2.

- In [103], 11.28%~52.41% of total power is consumed by SRS (re)configuration for UL positioning; Without SRS (re)configuration procedure, 55.07%/20.38%/11.85% power saving gains are achieved for DRX cycle of 1.28s/10.24s/20.48s.

Evaluation results on battery life assuming no SRS (re)configuration together with ultra-deep sleep state are provided by 11 sources ([92], [93], [96], [97], [98], [99], [101], [103], [108], [109], [110]) out of 19 sources, and the target requirement of 6~12 months is achieved by 10 out of 11 sources.

Evaluation results of minimized gaps between PRS/SRS/paging/reporting/synchronization are provided by 10 sources ([92], [93], [96], [98], [101], [102], [103], [108], [109], [110]) sources out of 19 sources, the following is observed:

- Minimizing gaps between PRS/SRS/paging/reporting/synchronization reduces power consumption, and results with minimized gaps between PRS/SRS/paging/reporting/synchronization provide power saving gains with respect to that without minimized gaps.

- From the evaluations,

- Comparative results with and without optimization of minimized gaps between PRS/SRS/paging/reporting/synchronization are provided by 3 sources ([102], [103], [110]):

- In [102], 8%~35% and 12.7%~44.5% power saving gains are achieved for DRX cycle 1.28s and 13.2% and 34% power saving gains for DRX cycle 10.24 sec, with minimized gaps between PRS/SRS/paging/reporting/synchronization with sleep states in TR 38.840 and ultra-deep sleep state option 1 with additional transition energy 10000.

- In [103], 5.48%~15.59%, 1.05%~3.60%, and 0.54%~1.96% power saving gains are achieved with minimized gaps between PRS/SRS/paging/reporting/synchronization for DRX cycle 1.28s, 10.24s, and 20.48s with sleep states in TR 38.840; 17.14%~33.33% power saving gains are achieved with minimized gaps between PRS/SRS/paging/reporting/synchronization for DRX cycle of 20.48s with ultra-deep sleep option 1.

- Results on battery life of assuming minimized gaps between PRS/SRS/paging/reporting/synchronization together with DRX cycle equal to or larger than 10.24s and ultra-deep sleep state are provided by 10 sources ([92], [93], [96], [98], [101], [102], [103], [108], [109], [110]), and the target requirement of 6~12 months is achieved by 9 sources.

Results of paging and/or PEI triggered positioning are further provided by 2 sources ([101], [108]) based on minimized gaps, which is beneficial to improve battery life as it allows a UE to perform positioning measurement and/or reporting behaviors:

- In [101], PEI triggered positioning improves battery life by 0.24~1.64 months, for DRX cycle 10.24s, with multiple ultra-deep sleep state options.

- In [108], paging triggered positioning improves battery life by 0.08 (6.02%) ~0.17 (7.98%) months for DL positioning, and by 0.02 (1.71%)~0.05 (1.96%) months for UL positioning; PEI triggered positioning improves battery life by 0.09 (6.77%) ~0.62 (29.11%) months for DL positioning, and by 0.04 (2.90%) ~0.47 (20.61%) months for UL positioning, for DRX cycle 10.24s and 20.48s, and ultra-deep sleep state option 1 with additional transition energy 10000.

Results on battery life of skipping paging reception are further provided by 1 source ([92] out of 19 sources, configuring a DRX cycle longer than positioning periodicity (up to 81.92s) or without paging reception can achieve 44.32%~89% power saving gain and is beneficial to improve battery life as it allows a UE to wake up using ultra-deep sleep state option 2 when only performing positioning related operations to achieve the target requirement of LPHAP. When UE wakes up to perform other operations than just positioning related operations, the UE uses ultra-deep sleep state option 1.

Results of only using TRS-based synchronization in adjacent slot to SRS is further provided by 1 source ([92]) under ultra-deep sleep state option 2 without paging reception, which achieves 23.33% power saving gain and further improves battery life with respect to that using SSB-based synchronization for UL positioning.

Evaluation results of simplified PRS configuration on both battery life and accuracy are provided by 1 source ([101]) out of 19 sources, the following is observed:

- In the case of K=1, C2=800, DRX cycle = 10.24s with ultra-deep sleep option 2, 1-symbol PRS can satisfy 6-month battery life but more than 1 symbol PRS cannot.

- The positioning accuracy of 1-symbol PRS and comb size > 12 barely reduces and can meet the accuracy requirement in some cases.

Table 6.4.3-1 presents a summary of the potential enhancements and their combinations considered by different sources as part of the study.

Table 6.4.3-1: Summary for results of overall enhancements for LPHAP

|  |  |  |  |
| --- | --- | --- | --- |
| Source | Evaluation case description | Target requirements are met – Yes/No | |
| 6 months | 12 months |
| [92] | UE-assisted DL positioning;  RS = 10.24s, paging = 10.24s, High SINR, CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000; | K = 1, Type A: NO | K = 1, Type A: NO |
| UE-based DL positioning;  RS = 10.24s, paging = 10.24s, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000; | K = 1, Type A: NO | K = 1, Type A: NO |
| UE-based DL positioning;  RS = 10.24s, paging = 20.48s, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000; | K = 1, Type A: NO | K = 1, Type A: NO |
| UE-based DL positioning;  RS = 10.24s, paging = 40.96s, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000; | K = 1, Type A: NO | K = 1, Type A: NO |
| UE-based DL positioning;  RS = 10.24s, paging = 81.92s, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000; | K = 1, Type A: NO | K = 1, Type A: NO |
| UE-based DL positioning;  RS = 10.24s, no paging, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000; | K = 1, Type A: NO | K = 1, Type A: NO |
| UL positioning;  RS = 10.24s, paging = 10.24s, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 10000; | K = 1, Type A: NO | K = 1, Type A: NO |
| UL positioning;  RS = 10.24s, paging = 20.48s, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 10000; | K = 1, Type A: NO | K = 1, Type A: NO |
| UL positioning;  RS = 10.24s, paging = 40.96s, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 10000; | K = 1, Type A: NO | K = 1, Type A: NO |
| UL positioning;  RS = 10.24s, paging = 81.92s, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized; No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 10000; | K = 1, Type A: NO | K = 1, Type A: NO |
| UL positioning;  RS = 10.24s, no paging, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 10000; | K = 1, Type A: NO | K = 1, Type A: NO |
| UE-based DL positioning;  RS = 10.24s, paging = 20.48s, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000 + Ultra-deep sleep option 2; | K = 1, Type A: NO | K = 1, Type A: NO |
| UE-based DL positioning;  RS = 10.24s, paging = 40.96s, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000 + Ultra-deep sleep option 2; | K = 1, Type A: NO | K = 1, Type A: NO |
| UE-based DL positioning;  RS = 10.24s, paging = 81.92s, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000 + Ultra-deep sleep option 2; | K = 1, Type A: NO | K = 1, Type A: NO |
| UE-based DL positioning;  RS = 10.24s, no paging, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 2; | K = 1, Type A: YES | K = 1, Type A: NO |
| UL positioning;  RS = 10.24s, paging = 20.48s, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 10000 + Ultra-deep sleep option 2; | K = 1, Type A: NO | K = 1, Type A: NO |
| UL positioning;  RS = 10.24s, paging = 40.96s, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 10000 + Ultra-deep sleep option 2; | K = 1, Type A: NO | K = 1, Type A: NO |
| UL positioning;  RS = 10.24s, paging = 81.92s, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 10000 + Ultra-deep sleep option 2; | K = 1, Type A: YES | K = 1, Type A: NO |
| UL positioning;  RS = 10.24s, no paging, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration;  Ultra-deep sleep option 2; | K = 1, Type A: YES | K = 1, Type A: YES |
| [93] | UE-assisted DL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR, CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: NO  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES |
| UE-assisted DL;  DRX = 30.72s, 1 RS per 1 DRX, High SINR, CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 2, Type A: YES  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES |
| UE-assisted DL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR, CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 5000 | K = 1, Type A: NO  K = 2, Type A: YES  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES |
| UE-assisted DL;  DRX = 30.72s, 1 RS per 1 DRX, High SINR, CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 5000 | K = 1, Type A: NO  K = 2, Type A: YES  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES |
| UE-based DL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: NO  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES |
| UE-based DL;  DRX = 30.72s, 1 RS per 1 DRX, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 2, Type A: YES  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES |
| UE-based DL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 5000 | K = 1, Type A: NO  K = 2, Type A: YES  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES |
| UE-based DL;  DRX = 30.72s, 1 RS per 1 DRX, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 5000 | K = 1, Type A: YES  K = 2, Type A: YES  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 2, Type A: YES  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES |
| UL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: NO  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES |
| UL;  DRX = 30.72s, 1 RS per 1 DRX, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 2, Type A: YES  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES |
| UL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration  Ultra-deep sleep option 1 w transition energy 5000 | K = 1, Type A: NO  K = 2, Type A: YES  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES |
| UL;  DRX = 30.72s, 1 RS per 1 DRX, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 5000 | K = 1, Type A: YES  K = 2, Type A: YES  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 2, Type A: YES  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES |
| [94] | UE-based DL;  DRX = 30.72s, 1 RS per 1 DRX, High SINR;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 1, Type B: YES | K = 1, Type A: NO  K = 1, Type B: YES |
| [96] | UE-assisted DL;  DRX = 10.24s, 1 RS per 1 DRX, High SINR, CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: NO  K = 1, Type B: NO  K = 2, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: NO  K = 1, Type B: NO  K = 2, Type B: NO  K = 4, Type B: YES |
| UE-based DL;  DRX = 10.24s, 1 RS per 1 DRX, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: NO  K = 1, Type B: NO  K = 2, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: NO  K = 1, Type B: NO  K = 2, Type B: NO  K = 4, Type B: YES |
| UL;  DRX = 10.24s, 1 RS per 1 DRX, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000  No SRS (re)configuration; | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: NO  K = 1, Type B: NO  K = 2, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: NO  K = 1, Type B: NO  K = 2, Type B: NO  K = 4, Type B: YES |
| [97] | UE-assisted DL;  DRX = 10.24s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: NO  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: NO  K = 1, Type B: NO  K = 2, Type B: YES  K = 4, Type B: YES |
| UE-assisted DL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: NO  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES |
| UE-assisted DL;  DRX = 30.72s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 2, Type A: YES  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES |
| UE-assisted DL;  DRX = 10.24s, 1 RS per 1 DRX, Low SINR; CG-SDT for reporting  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: NO  K = 1, Type B: NO  K = 2, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: NO  K = 1, Type B: NO  K = 2, Type B: NO  K = 4, Type B: YES |
| UE-assisted DL;  DRX = 20.48s, 1 RS per 1 DRX, Low SINR; CG-SDT for reporting  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: NO  K = 1, Type B: NO  K = 2, Type B: YES  K = 4, Type B: YES |
| UE-assisted DL;  DRX = 30.72s, 1 RS per 1 DRX, Low SINR; CG-SDT for reporting  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: NO  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES |
| UE-based DL;  DRX = 10.24s, 1 RS per 1 DRX, High SINR;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: NO  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: NO  K = 1, Type B: NO  K = 2, Type B: YES  K = 4, Type B: YES |
| UE-based DL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: NO  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES |
| UE-based DL;  DRX = 30.72s, 1 RS per 1 DRX, High SINR;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 2, Type A: YES  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES |
| UE-based DL;  DRX = 10.24s, 1 RS per 1 DRX, Low SINR;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: NO  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: NO  K = 1, Type B: NO  K = 2, Type B: YES  K = 4, Type B: YES |
| UE-based DL;  DRX = 20.48s, 1 RS per 1 DRX, Low SINR;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: NO  K = 1, Type B: NO  K = 2, Type B: YES  K = 4, Type B: YES |
| UE-based DL;  DRX = 30.72s, 1 RS per 1 DRX, Low SINR;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 2, Type A: YES  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES |
| UL;  DRX = 10.24s, 1 RS per 1 DRX, High SINR;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 10000; | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: NO  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: NO  K = 1, Type B: NO  K = 2, Type B: YES  K = 4, Type B: YES |
| UL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: NO  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES |
| UL;  DRX = 30.72s, 1 RS per 1 DRX, High SINR;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 2, Type A: YES  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES |
| UL;  DRX = 10.24s, 1 RS per 1 DRX, Low SINR;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: NO  K = 1, Type B: NO  K = 2, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: NO  K = 1, Type B: NO  K = 2, Type B: NO  K = 4, Type B: YES |
| UL;  DRX = 20.48s, 1 RS per 1 DRX, Low SINR;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: NO  K = 1, Type B: NO  K = 2, Type B: YES  K = 4, Type B: YES |
| UL;  DRX = 30.72s, 1 RS per 1 DRX, Low SINR;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: NO  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES |
| [98] | UE-assisted DL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: YES  K = 1, Type B: YES | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: NO  K = 1, Type B: YES |
| UE-assisted DL;  DRX = 30.72s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 2, Type A: YES  K = 4, Type A: YES | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: YES |
| UE-assisted DL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting;  Ultra-deep sleep option 2 | K = 1, Type A: YES | K = 1, Type A: YES |
| UE-based DL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: YES  K = 1, Type B: YES | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: NO  K = 1, Type B: YES |
| UE-based DL;  DRX = 30.72s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 2, Type A: YES  K = 4, Type A: YES | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: YES |
| UE-based DL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 2 | K = 1, Type A: YES | K = 1, Type A: YES |
| UL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: YES  K = 1, Type B: YES | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: NO  K = 1, Type B: YES |
| UL;  DRX = 30.72s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 2, Type A: YES  K = 4, Type A: YES | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: YES |
| UL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration;  Ultra-deep sleep option 2 | K = 1, Type A: YES | K = 1, Type A: YES |
| [99] | UE-assisted DL;  DRX = 10.24s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 4, Type A: NO | K = 1, Type A: NO  K = 4, Type A: NO |
| UE-assisted DL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 4, Type A: YES | K = 1, Type A: NO  K = 4, Type A: NO |
| UE-assisted DL;  DRX = 30.72s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 4, Type A: YES | K = 1, Type A: NO  K = 4, Type A: YES |
| UE-assisted DL;  DRX = 10.24s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting;  Ultra-deep sleep option 1 w transition energy 5000 | K = 1, Type A: NO  K = 4, Type A: YES | K = 1, Type A: NO  K = 4, Type A: NO |
| UE-assisted DL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting;  Ultra-deep sleep option 1 w transition energy 5000 | K = 1, Type A: NO  K = 4, Type A: YES | K = 1, Type A: NO  K = 4, Type A: YES |
| UE-assisted DL;  DRX = 30.72s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting;  Ultra-deep sleep option 1 w transition energy 5000 | K = 1, Type A: NO  K = 4, Type A: YES | K = 1, Type A: NO  K = 4, Type A: YES |
| UE-based DL;  DRX = 10.24s, 1 RS per 1 DRX, High SINR;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 4, Type A: NO | K = 1, Type A: NO  K = 4, Type A: NO |
| UE-based DL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 4, Type A: YES | K = 1, Type A: NO  K = 4, Type A: NO |
| UE-based DL;  DRX = 30.72s, 1 RS per 1 DRX, High SINR;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 4, Type A: YES | K = 1, Type A: NO  K = 4, Type A: YES |
| UE-based DL;  DRX = 10.24s, 1 RS per 1 DRX, High SINR;  Ultra-deep sleep option 1 w transition energy 5000 | K = 1, Type A: NO  K = 4, Type A: YES | K = 1, Type A: NO  K = 4, Type A: NO |
| UE-based DL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR;  Ultra-deep sleep option 1 w transition energy 5000 | K = 1, Type A: NO  K = 4, Type A: YES | K = 1, Type A: NO  K = 4, Type A: YES |
| UE-based DL;  DRX = 30.72s, 1 RS per 1 DRX, High SINR;  Ultra-deep sleep option 1 w transition energy 5000 | K = 1, Type A: NO  K = 4, Type A: YES | K = 1, Type A: NO  K = 4, Type A: YES |
| UL;  DRX = 10.24s, 1 RS per 1 DRX, High SINR;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 4, Type A: NO | K = 1, Type A: NO  K = 4, Type A: NO |
| UL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 4, Type A: YES | K = 1, Type A: NO  K = 4, Type A: NO |
| UL;  DRX = 30.72s, 1 RS per 1 DRX, High SINR;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 4, Type A: YES | K = 1, Type A: NO  K = 4, Type A: YES |
| UL;  DRX = 10.24s, 1 RS per 1 DRX, High SINR;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 5000 | K = 1, Type A: NO  K = 4, Type A: YES | K = 1, Type A: NO  K = 4, Type A: NO |
| UL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 5000 | K = 1, Type A: NO  K = 4, Type A: YES | K = 1, Type A: NO  K = 4, Type A: YES |
| UL;  DRX = 30.72s, 1 RS per 1 DRX, High SINR;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 5000 | K = 1, Type A: YES  K = 4, Type A: YES | K = 1, Type A: NO  K = 4, Type A: YES |
| [101] | UE-assisted DL;  DRX = 10.24s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 4, Type A: NO  K = 0.5, Type B: NO  K = 1, Type B: YES | K = 1, Type A: NO  K = 4, Type A: NO  K = 0.5, Type B: NO  K = 1, Type B: NO |
| UE-assisted DL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 4, Type A: YES  K = 0.5, Type B: YES  K = 1, Type B: YES | K = 1, Type A: NO  K = 4, Type A: NO  K = 0.5, Type B: NO  K = 1, Type B: YES |
| UE-assisted DL;  DRX = 10.24s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 5000 | K = 1, Type A: NO  K = 4, Type A: YES  K = 0.5, Type B: NO  K = 1, Type B: YES | K = 1, Type A: NO  K = 4, Type A: NO  K = 0.5, Type B: NO  K = 1, Type B: NO |
| UE-assisted DL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 5000 | K = 1, Type A: NO  K = 4, Type A: YES  K = 0.5, Type B: YES  K = 1, Type B: YES | K = 1, Type A: NO  K = 4, Type A: YES  K = 0.5, Type B: NO  K = 1, Type B: YES |
| UE-assisted DL;  DRX = 10.24s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 2 | K = 0.5, Type A: NO  K = 1, Type A: NO | K = 0.5, Type A: NO  K = 1, Type A: NO |
| UE-assisted DL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 2 | K = 0.5, Type A: NO  K = 1, Type A: YES | K = 0.5, Type A: NO  K = 1, Type A: NO |
| UE-based DL;  DRX = 10.24s, 1 RS per 1 DRX, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 4, Type A: NO  K = 0.5, Type B: NO  K = 1, Type B: YES | K = 1, Type A: NO  K = 4, Type A: NO  K = 0.5, Type B: NO  K = 1, Type B: YES |
| UE-based DL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 4, Type A: YES  K = 0.5, Type B: YES  K = 1, Type B: YES | K = 1, Type A: NO  K = 4, Type A: NO  K = 0.5, Type B: NO  K = 1, Type B: YES |
| UE-based DL;  DRX = 10.24s, 1 RS per 1 DRX, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 5000 | K = 1, Type A: NO  K = 4, Type A: YES  K = 0.5, Type B: YES  K = 1, Type B: YES | K = 1, Type A: NO  K = 4, Type A: NO  K = 0.5, Type B: NO  K = 1, Type B: YES |
| UE-based DL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 5000 | K = 1, Type A: NO  K = 4, Type A: YES  K = 0.5, Type B: YES  K = 1, Type B: YES | K = 1, Type A: NO  K = 4, Type A: YES  K = 0.5, Type B: YES  K = 1, Type B: YES |
| UE-based DL;  DRX = 10.24s, 1 RS per 1 DRX, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 2 | K = 0.5, Type A: NO  K = 1, Type A: YES | K = 0.5, Type A: NO  K = 1, Type A: NO |
| UE-based DL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 2 | K = 0.5, Type A: YES  K = 1, Type A: YES | K = 0.5, Type A: NO  K = 1, Type A: YES |
| UL;  DRX = 10.24s, 1 RS per 1 DRX, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 4, Type A: NO  K = 0.5, Type B: NO  K = 1, Type B: YES | K = 1, Type A: NO  K = 4, Type A: NO  K = 0.5, Type B: NO  K = 1, Type B: NO |
| UL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 4, Type A: YES  K = 0.5, Type B: YES  K = 1, Type B: YES | K = 1, Type A: NO  K = 4, Type A: NO  K = 0.5, Type B: NO  K = 1, Type B: YES |
| UL;  DRX = 10.24s, 1 RS per 1 DRX, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 5000 | K = 1, Type A: NO  K = 4, Type A: YES  K = 0.5, Type B: YES  K = 1, Type B: YES | K = 1, Type A: NO  K = 4, Type A: NO  K = 0.5, Type B: NO  K = 1, Type B: YES |
| UL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 5000 | K = 1, Type A: NO  K = 4, Type A: YES  K = 0.5, Type B: YES  K = 1, Type B: YES | K = 1, Type A: NO  K = 4, Type A: YES  K = 0.5, Type B: YES  K = 1, Type B: YES |
| UL;  DRX = 10.24s, 1 RS per 1 DRX, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration;  Ultra-deep sleep option 2 | K = 0.5, Type A: NO  K = 1, Type A: YES | K = 0.5, Type A: NO  K = 1, Type A: NO |
| UL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration;  Ultra-deep sleep option 2 | K = 0.5, Type A: YES  K = 1, Type A: YES | K = 0.5, Type A: NO  K = 1, Type A: YES |
| DL+UL;  DRX = 10.24s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 4, Type A: NO  K = 0.5, Type B: NO  K = 1, Type B: YES | K = 1, Type A: NO  K = 4, Type A: NO  K = 0.5, Type B: NO  K = 1, Type B: NO |
| DL+UL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 4, Type A: YES  K = 0.5, Type B: YES  K = 1, Type B: YES | K = 1, Type A: NO  K = 4, Type A: NO  K = 0.5, Type B: NO  K = 1, Type B: YES |
| DL+UL;  DRX = 10.24s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 5000 | K = 1, Type A: NO  K = 4, Type A: YES  K = 0.5, Type B: YES  K = 1, Type B: YES | K = 1, Type A: NO  K = 4, Type A: NO  K = 0.5, Type B: NO  K = 1, Type B: YES |
| DL+UL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 5000 | K = 1, Type A: NO  K = 4, Type A: YES  K = 0.5, Type B: YES  K = 1, Type B: YES | K = 1, Type A: NO  K = 4, Type A: YES  K = 0.5, Type B: NO  K = 1, Type B: YES |
| DL+UL;  DRX = 10.24s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration;  Ultra-deep sleep option 2 | K = 0.5, Type A: NO  K = 1, Type A: YES | K = 0.5, Type A: NO  K = 1, Type A: NO |
| DL+UL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration;  Ultra-deep sleep option 2 | K = 0.5, Type A: NO  K = 1, Type A: YES | K = 0.5, Type A: NO  K = 1, Type A: NO |
| [102] | UE-assisted DL;  DRX = 1.28s, 1 RS per 1 DRX, High SINR, CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 4, Type A: NO  K = 1, Type B: NO  K = 4, Type B: YES | K = 1, Type A: NO  K = 4, Type A: NO  K = 1, Type B: NO  K = 4, Type B: NO |
| UE-assisted DL;  DRX = 1.28s, 1 RS per 8 DRX, High SINR, CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 4, Type A: NO  K = 1, Type B: NO  K = 4, Type B: YES | K = 1, Type A: NO  K = 4, Type A: NO  K = 1, Type B: NO  K = 4, Type B: NO |
| UE-assisted DL;  DRX = 10.24, 1 RS per 1 DRX, High SINR, CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 4, Type A: NO  K = 1, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 4, Type A: NO  K = 1, Type B: NO  K = 4, Type B: YES |
| [103] | UE-assisted DL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: NO  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES |
| UE-assisted DL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 5000 | K = 1, Type A: NO  K = 2, Type A: YES  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES |
| UE-assisted DL;  DRX = 20.48s, 1 RS per 1 DRX, no paging, High SINR; CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 2 | K = 1, Type A: YES  K = 2, Type A: YES  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 2, Type A: YES  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES |
| UE-based DL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: NO  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES |
| UE-based DL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 5000 | K = 1, Type A: NO  K = 2, Type A: YES  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES |
| UE-based DL;  DRX = 20.48s, 1 RS per 1 DRX, no paging, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 2 | K = 1, Type A: YES  K = 2, Type A: YES  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES | K = 1, Type A: YES  K = 2, Type A: YES  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES |
| UL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: NO  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES |
| UL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 5000 | K = 1, Type A: NO  K = 2, Type A: YES  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 2, Type A: NO  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES |
| UL;  DRX = 20.48s, 1 RS per 1 DRX, no paging, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration;  Ultra-deep sleep option 2 | K = 1, Type A: YES  K = 2, Type A: YES  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES | K = 1, Type A: YES  K = 2, Type A: YES  K = 4, Type A: YES  K = 1, Type B: YES  K = 2, Type B: YES  K = 4, Type B: YES |
| [108] | UE-assisted DL;  DRX = 1.28s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO | K = 1, Type A: NO |
| UE-assisted DL;  DRX = 1.28s, 1 RS per 8 DRX, High SINR; CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO | K = 1, Type A: NO |
| UE-assisted DL;  DRX = 10.24s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO | K = 1, Type A: NO |
| UE-assisted DL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO | K = 1, Type A: NO |
| UE-assisted DL;  DRX = 1.28s, 1 RS per 1 DRX, Low SINR; RA-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO | K = 1, Type A: NO |
| UE-assisted DL;  DRX = 1.28s, 1 RS per 8 DRX, Low SINR; RA-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO | K = 1, Type A: NO |
| UE-assisted DL;  DRX = 10.24s, 1 RS per 1 DRX, Low SINR; RA-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO | K = 1, Type A: NO |
| UE-assisted DL;  DRX = 20.48s, 1 RS per 1 DRX, Low SINR; RA-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO | K = 1, Type A: NO |
| UL;  DRX = 1.28s, 1 RS per 1 DRX, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO | K = 1, Type A: NO |
| UL;  DRX = 1.28s, 1 RS per 8 DRX, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO | K = 1, Type A: NO |
| UL;  DRX = 10.24s, 1 RS per 1 DRX, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO | K = 1, Type A: NO |
| UL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO | K = 1, Type A: NO |
| UL;  DRX = 1.28s, 1 RS per 1 DRX, Low SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO | K = 1, Type A: NO |
| UL;  DRX = 1.28s, 1 RS per 8 DRX, Low SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO | K = 1, Type A: NO |
| UL;  DRX = 10.24s, 1 RS per 1 DRX, Low SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO | K = 1, Type A: NO |
| UL;  DRX = 20.48s, 1 RS per 1 DRX, Low SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO | K = 1, Type A: NO |
| [109] | UE-assisted DL;  DRX = 10.24s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 4, Type A: NO  K = 1, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 4, Type A: NO  K = 1, Type B: NO  K = 4, Type B: YES |
| UE-assisted DL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 4, Type A: YES  K = 1, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 4, Type A: NO  K = 1, Type B: YES  K = 4, Type B: YES |
| UE-assisted DL;  DRX = 30.72s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 4, Type A: YES  K = 1, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 4, Type A: YES  K = 1, Type B: YES  K = 4, Type B: YES |
| UE-based DL;  DRX = 10.24s, 1 RS per 1 DRX, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 4, Type A: NO  K = 1, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 4, Type A: NO  K = 1, Type B: NO  K = 4, Type B: YES |
| UE-based DL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 4, Type A: YES  K = 1, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 4, Type A: NO  K = 1, Type B: YES  K = 4, Type B: YES |
| UE-based DL;  DRX = 30.72s, 1 RS per 1 DRX, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 4, Type A: YES  K = 1, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 4, Type A: YES  K = 1, Type B: YES  K = 4, Type B: YES |
| UL;  DRX = 10.24s, 1 RS per 1 DRX, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 4, Type A: NO  K = 1, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 4, Type A: NO  K = 1, Type B: NO  K = 4, Type B: YES |
| UL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 4, Type A: YES  K = 1, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 4, Type A: NO  K = 1, Type B: YES  K = 4, Type B: YES |
| UL;  DRX = 30.72s, 1 RS per 1 DRX, High SINR;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 4, Type A: YES  K = 1, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 4, Type A: YES  K = 1, Type B: YES  K = 4, Type B: YES |
| DL+UL;  DRX = 10.24s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 4, Type A: NO  K = 1, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 4, Type A: NO  K = 1, Type B: NO  K = 4, Type B: YES |
| DL+UL;  DRX = 20.48s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 4, Type A: YES  K = 1, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 4, Type A: NO  K = 1, Type B: YES  K = 4, Type B: YES |
| DL+UL;  DRX = 30.72s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO  K = 4, Type A: YES  K = 1, Type B: YES  K = 4, Type B: YES | K = 1, Type A: NO  K = 4, Type A: YES  K = 1, Type B: YES  K = 4, Type B: YES |
| [110] | UE-assisted DL;  DRX = 1.28s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO | K = 1, Type A: NO |
| UE-assisted DL;  DRX = 10.24s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: NO | K = 1, Type A: NO |
| UL;  DRX = 10.24s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: YES | K = 1, Type A: NO |
| UL;  DRX = 30.72s, 1 RS per 1 DRX, High SINR; CG-SDT for reporting;  Gaps between PRS/SRS/paging/reporting is minimized;  No SRS (re)configuration  Ultra-deep sleep option 1 w transition energy 10000 | K = 1, Type A: YES | K = 1, Type A: YES |

Evaluation results on the battery life of overall enhancements including at least one or combinations of DRX cycle beyond 10.24s, ultra-deep sleep state, minimized gaps between PRS/SRS/paging/reporting/synchronization, and no SRS (re)configuration procedure, are provided by 13 sources ([92], [93], [94], [96], [97], [98], [99], [101],[102], [103], [108], [109], [110]) out of 19 sources.

For the evaluation with ultra-deep sleep state option 1 with additional transition energy 10000, results are provided by 13 sources ([92], [93], [94], [96], [97], [98], [99], [101],[102], [103], [108], [109], [110]) out of 19 sources, and the following are observed:

- For the baseline LPHAP Type A device with battery capacity C2 of 800mAh, the target requirement of 6~12 months is achieved by 1 source ([110]) with baseline implementation factor K = 1, and is achieved by 8 sources ([93], [94], [97], [98], [99], [101], [103], [109]) with optional implementation factor K.

- For the optional LPHAP Type B device with battery capacity C2 of 4500mAh, the target requirement of 6~12 months is achieved by 8 sources ([93], [94], [97], [98], [99], [101], [103], [109]) with baseline implementation factor K = 1, and is achieved by 6 sources ([93], [96], [97], [101], [103], [109]) with optional implementation factor K.

For the evaluation with ultra-deep sleep state option 1 with additional transition energy 5000, results are provided by 4 sources ([93], [99], [101], [103]) out of 19 sources, and the following are observed:

- For the baseline LPHAP Type A device with battery capacity C2 of 800mAh, the target requirement of 6~12 months is achieved by 2 sources ([93], [99]) with baseline implementation factor K = 1, and is achieved by 4 sources ([93], [99], [101], [103]) with optional implementation factor K.

- For the optional LPHAP Type B device with battery capacity C2 of 4500mAh, the target requirement of 6~12 months is achieved by 3 sources ([93], [101], [103]) with baseline implementation factor K = 1, and is achieved by 3 sources ([93], [101], [103]) with optional implementation factor K.

For ultra-deep sleep state option 2 (including TDM-ed with ultra-deep sleep option 1 for power cycles in which paging reception is required), results are provided by 4 sources ([92], [98], [101], [103]) out of 19 sources, and the following are observed:

- For the baseline LPHAP Type A device with battery capacity C2 of 800mAh, the target requirement of 6~12 months is achieved by 4 sources ([92], [98], [101], [103]) with baseline implementation factor K = 1, and is achieved by 2 sources ([101], [103]) with optional implementation factor K.

- For the optional LPHAP Type B device with battery capacity C2 of 4500mAh, the target requirement of 6~12 months is achieved by 1 source ([103]) with baseline implementation factor K = 1, and is achieved by 1 source ([103]) with optional implementation factor K.

### 6.4.4 Potential specification impact for low power high accuracy positioning

Extending DRX cycle beyond 10.24s was studied and found beneficial towards meeting the battery life requirement for LPHAP and is recommended for normative work on Rel-18 positioning enhancements from RAN1's perspective.

NOTE: No RAN1 specification impact has been identified.

For UL and DL+UL positioning for UEs in RRC\_INACTIVE state, the details of solutions for enhancements on SRS for positioning to avoid frequent RRC connection for SRS (re)configuration can be further discussed during normative work, which may include but are not limited to one or combinations of the following:

- SRS for positioning configurations in multiple cells.

- NOTE: Details including issues such as interference, timing advance, spatial relation information, pathloss reference and common SRS parameters across multiple cells can be further discussed during normative work.

- Pre-configuration of one or multiple SRS for positioning configurations.

- SRS for positioning activation/request procedure(s).

In addition to the above, specification impact can be expected from the perspective of higher layers to support the potential enhancements for LPHAP as detailed in Clause 6.4.2.2.

## 6.5 Positioning of UEs with reduced capabilities

### 6.5.0 Study objectives

The scope of the study on positioning for RedCap UEs is defined in the SID [7] as:

- Evaluation of positioning performance of existing positioning procedures and measurements with RedCap UEs.

- Based on the evaluations, assessment of the necessity of enhancements and, if needed, identification of enhancements to help address limitations associated with RedCap UEs.

For the purpose of the study of positioning performance for UEs with Reduced Capabilities (RedCap UEs), the following target performance requirements are considered:

For commercial use cases for both indoor and outdoor scenarios

- Horizontal positioning accuracy: (< 3 m) for 90% of UEs

- Vertical positioning accuracy: (< 3 m) for 90% of UEs.

For IIoT use cases:

- Horizontal positioning accuracy: (< 1 m) for 90% of UEs

- Vertical positioning accuracy: (< 3 m) for 90% of UEs.

For the above target requirements for evaluations, it should be noted that the target positioning requirements may not necessarily be achieved for all scenarios and use cases. Further, all positioning techniques may not achieve all positioning requirements in all scenarios.

### 6.5.1 Potential solutions for positioning for RedCap UEs

Potential enhancements to UL SRS for positioning to enable transmitter frequency hopping are studied, including but not limited to partial overlapping between hops, hopping bandwidth, and time gap between frequency hopping.

Potential enhancements to DL PRS to enable transmitter or receiver frequency hopping are studied, including but not limited to impact on processing capability, hopping bandwidth in the positioning frequency layer, time gap between frequency hopping, measurement period, and partial overlapping between hops.

The potential benefits and performance gains of frequency hopping of the DL PRS and UL SRS are investigated, taking into account at least the following:

- The impact of Doppler, phase offset, timing offset, power imbalance among hops

- RedCap UE capability and complexity considerations

- Impact of RF retuning during frequency hopping

- Details of frequency hopping (including Tx hopping and/or Rx hopping, BWP switching).

In addition, use of NR carrier phase positioning is also studied and evaluated for enabling high accuracy positioning performance for RedCap UEs.

### 6.5.2 Summary of evaluations for positioning for RedCap UEs

The methodology for the evaluation of positioning performance for RedCap UEs can be found in Annex A.5.

For the baseline performance of positioning for Redcap UEs in IIOT scenarios, based on the results provided by a majority of 19 sources, for InF-SH in FR1, the horizontal positioning requirement for IIOT use cases is not achieved by Rel.17 solutions using 5 MHz or 20 MHz of bandwidth.

- Sources in [111], [72] show that UL TDOA cannot meet the requirement.

- Sources in [71], [72] show that multi-RTT cannot meet the requirement.

- Sources in [57], [58], [59], [60], [62], [65], [67], [72], [115], [127] show that DL-TDOA cannot meet the requirement.

- Source in [55] shows that the requirement can be met using 20 MHz of bandwidth.

- Source in [55] shows that the requirement cannot be met using 5 MHz of bandwidth.

- Source in [125] shows that UL-AoA cannot meet the requirement.

- Source in [128] shows that DL-AoD cannot meet the requirement.

Based on the results provided by 2 sources ([62], [71]) out of 19 sources, for InF-SH in FR2, the horizontal positioning requirement for IIOT use cases is achieved by Rel.17 solutions using 100 MHz of bandwidth.

- Source in [62] shows that DL-TDOA can meet the requirement.

- Source in [71] shows that multi-RTT can meet the requirement.

Based on the result provided by the following source, for InF-DH in FR1, the horizontal positioning requirement for IIOT use cases is not achieved by Rel.17 solutions using 20 MHz of bandwidth.

- Source in [60], [117], [118] show that the requirements for IIOT use cases cannot be met for InF-DH.

For the baseline performance of positioning for Redcap UEs in commercial scenarios,

- based on the results provided by [111] and [113], for UMi in FR1, the horizontal positioning requirement for commercial use cases is not achieved by Rel.17 solutions using 20 MHz of bandwidth and UL TDOA.

- based on the results provided by [67], [113], [118], and [127], for UMi in FR1, the horizontal positioning requirement for commercial use cases is not achieved by Rel.17 solutions using 5MHz or 20 MHz of bandwidth and DL TDOA.

- based on the results provided by [71] and [113], for UMi in FR1, the horizontal positioning requirement for commercial use cases is not achieved by Rel.17 solutions using 20 MHz or 5 MHz of bandwidth and multi-RTT.

Regarding the performance for positioning of Redcap UEs using frequency hopping in IIoT scenarios, considering phase offset between hops:

- In FR1, based on the results provided by the following sources:

- If the phase offset between hops in frequency hopping is compensated, for InF-SH, the positioning requirement for IIOT use cases can be achieved using frequency hopping with partial overlap for the purpose of phase offset compensation,

- Results in [111] show that UL TDOA can meet the requirements.

- Results in [111], [62], and [113] show that DL TDOA can meet the requirements.

- Results in [55], show that the requirement cannot be met, even if the phase is compensated.

- If the phase offset between hops in Frequency hopping is not compensated,

- Results in [62] and [119] show that DL TDOA can meet the requirements if the random phase offset is set to be equal or smaller than 0.4π.

- Results in [121] show that DL TDOA cannot meet the requirement with the random phase offset distributed from [-π, π].

- In FR2, based on the results provided by the following sources:

- Results in [71] show that the requirements can be met even if the phase is not compensated.

- Results in [62] show that PRS frequency hopping can improve positioning performance if the random phase between hops can be adjusted in FR2, InF-SH scenario.

NOTE: Sources used different combinations of number of hops, gap size between hops and partial overlap sizes in their evaluations.

Regarding the performance for positioning of Redcap UEs using Rx hopping for reception of the DL PRS or Tx hopping for transmission of the UL SRS in IIoT scenarios, considering time gap between hops:

- In FR1 for InF SH, based on the results provided by the following sources:

- For UL-TDOA, results in [111] shows that the requirement can be met for a gap of 1ms and cannot be met for a gap of 5ms.

- For DL-TDOA, results in [111] shows that the requirement can be met for a gap of 1ms and cannot be met for a gap of 5ms.

- For DL-TDOA, results in [113] shows that the requirement can be met for a gap of 4ms.

- For DL-TDOA, results in [118] shows that the requirement can be met for a gap of 1ms and cannot be met for a gap of more than 2ms.

- For DL-TDOA, results in [132] shows that the requirement can be met for a gap of 5ms.

Regarding the performance for positioning of Redcap UEs using Rx hopping for reception of the DL PRS in IIoT scenarios, considering timing error during the frequency hopping:

- In FR1, for InF-SH, based on the results provided by the following sources:

- For DL-TDOA, results in [113] shows the IIOT horizontal accuracy requirement cannot be met if the timing error is 3ns.

- For DL-TDOA, results in [118] shows the IIOT horizontal accuracy requirement can be met if the timing error is 2ns, but cannot be met if the timing error is 3ns.

Regarding the performance for positioning of Redcap UEs using frequency hopping in commercial scenarios, considering phase offset between hops:

- In FR1, based on the results provided ([111], [71]), for the UMi positioning requirement for commercial use cases, positioning accuracy improvement is observed by two sources when the phase offset between hops in Frequency hopping is considered, if frequency hopping with partial overlap for the purpose of phase offset compensation is used, and if the phase offset is compensated.

- Results in [111] show that positioning accuracy improvement is observed with UL TDOA with phase offset compensation, but requirements are not met.

- Results in [111] show that positioning accuracy improvement is observed with DL TDOA with phase offset compensation, but requirements are not met.

- Results in [71] show that positioning accuracy improvement is observed with Multi RTT with phase offset compensation, but requirements are not met.

NOTE: Sources used different combinations of number of hops, gap size between hops and partial overlap sizes in their evaluations.

Regarding the performance for positioning of Redcap UEs using Rx hopping for reception of the DL PRS or Tx hopping for transmission of the UL SRS in IIoT or commercial scenarios, considering time gap between hops together with UE speed:

- In FR1, for InF-SH based on the results provided by the following sources:

- For UL-TDOA, results in [111] shows that the horizontal accuracy requirement can be met for a gap of 140us for UE speed of up to 120km/h.

- For DL-TDOA, results in [113] shows that the horizontal accuracy requirement can be met for a gap of 2 or 4 ms for UE speed of up to 30km/h, and cannot be met for 60km/h.

- For DL-TDOA, results in [118] shows that the requirement can be met for a gap of 0.1ms for UE speed of up to 150km/h; the horizontal accuracy requirement can be met for a gap of 0.2ms for UE speed of up to 60km/h; the horizontal accuracy requirement can be met for a gap of 0.5ms for UE speed of up to 30km/h; the horizontal accuracy requirement can be met for a gap of 1ms, 2ms, 5ms for UE speed of up to 3km/h.

- In FR1, for UMi, based on the results provided by the following sources:

- For multi-RTT, results in [128] shows that the requirement for commercial scenarios cannot be met, but performance of frequency hopping with 5 hops and 640 µsec switching gap degrades only marginally for speeds of 30 or 60 kmh over 3 km/h.

In FR1, for InF-SH, the performance of carrier phase positioning with RedCap UEs using 20MHz of bandwidth was evaluated without modeling the agreed error sources. Based on the reported results the following observations are made:

- Results in [113] shows that with an estimated integer ambiguity, a redcap UE using CPP cannot meet the IIOT requirements.

- Results in [113], [114] show that a redcap UE using CPP can meet the IIOT requirement under ideal conditions and known integer ambiguity.

- Results in [118] shows that a redcap UE using CPP cannot meet the IIOT requirements with a fixed search range of integer ambiguity.

- Results in [127] shows that a redcap UE using CPP can meet the IIOT requirements, under some conditions for integer ambiguity resolution.

- Results in [128] shows that a redcap UE using phase-difference AoD improves performance over RSRPP-based AoD but cannot meet the IIoT requirements.

- Results in [132] shows that a redcap UE using CPP can meet the IIOT requirements if frequency hopping enhancements are also used and cannot meet the IIOT requirements without enhancements.

### 6.5.3 Potential specification impact for positioning for RedCap UEs

From RAN1's perspective, the following have been identified for potential specification impact to support NR positioning for RedCap UEs:

- Maximum tolerable phase error, timing gap, and timing error between hops.

- Considerations for IIoT, commercial, Public Safety and V2X scenarios, and UE capabilities.

- Details on the Tx or Rx hopping pattern(s), including frequency overlapping between hops, if supported.

# 7 Conclusions

## 7.0 Study objectives

The scope of the Rel-18 study item on expanded NR positioning enhancements included various aspects of positioning features in NR systems involving the Uu and PC5 interfaces. These included sidelink (SL) positioning, including evaluation of bandwidth requirements, and performance for absolute and relative positioning, and ranging distance and angle determination; positioning enhancements for improved integrity, accuracy, and power efficiency via defining integrity characteristics for RAT-dependent positioning, PRS/SRS bandwidth aggregation, NR carrier phase positioning, LPHAP; and support of positioning for UEs with Reduced Capabilities (RedCap UEs).

Based on the studies conducted in RAN working groups, the following conclusions are made.

## 7.1 Scenarios and requirements for sidelink positioning

Based on the study, the identified scenarios for the prioritized use-cases and related target requirements are summarized as in Table 7.1-1.

Table 7.1-1: Target accuracy requirements for SL positioning

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **SL Positioning KPIs** | **V2X** | **Public Safety** | **IIoT** | **Commercial** |
| Horizontal Positioning Accuracy | Set A (similar to "Set 2" defined in [3]): 1.5 m for 90% of UEs (absolute or relative) | 1 m for 90% of UEs (absolute or relative) | Set A: 1 m for 90% of UEs (absolute or relative) | 1 m for 90% of UEs (absolute or relative) |
| Set B: 0.2 m for 90% of UEs (absolute or relative) |
| Set B (similar to "Set 3" defined in [3]): 0.5 m for 90% of UEs (absolute or relative) |
| Vertical Positioning Accuracy | Set A: 3 m for 90% of UEs (absolute or relative) | 2 m (absolute or relative between 2 UEs) for 90% of UEs | Set A: 1 m for 90% of UEs (absolute or relative) | 2 m for 90% of UEs (absolute or relative) |
| Set B: 2 m for 90% of UEs (absolute or relative) | 0.3 m (relative positioning change for 1 UE) for 90% of UEs | Set B: 0.2 m for 90% of UEs (absolute or relative) |
| Relative Speed | - | Up to 30 km/h | Up to 30 km/h | Up to 30 km/h |
| Angle Accuracy | Set A: Y = ±15° for 90% of the UEs | | | |
| Set B: Y = ±8° for 90% of the UEs | | | |
| NOTE 1: For evaluated SL positioning methods, the performance results in Annex B.1 are described in terms of:  - whether each of the two requirements are satisfied, and  - %-ile of UEs satisfying the target positioning accuracy for a requirement that may not be satisfied with 90%.  NOTE 2: Target positioning requirements may not necessarily be reached for all scenarios and deployments  NOTE 3: All positioning techniques may not achieve all positioning requirements in all scenarios. | | | | |

## 7.2 Bandwidth requirements for sidelink positioning

Performance evaluation results reported as part of the study indicate that, depending on sources, use-cases, scenarios, assumptions, and positioning methods used, the identified target requirements can be satisfied with different values of SL PRS bandwidth choices.

- For FR1 spectrum:

- For certain sources and combinations of use-cases, scenarios, assumptions, and positioning methods, some target requirements can be satisfied with SL PRS bandwidths of 20 MHz or 40 MHz.

- For certain sources and other combinations of use-cases, scenarios, assumptions, and positioning methods, some target requirements require SL PRS bandwidth of 100 MHz or may not be satisfied even with SL PRS bandwidth of 100 MHz.

- For FR2 spectrum, based on submitted results from up to two sources:

- For certain sources and combinations of use-cases, scenarios, assumptions, and positioning methods, some target requirements can be satisfied with SL PRS bandwidth of 200 MHz.

- For certain sources and combinations of use-cases, scenarios, assumptions, and positioning methods, some of the target requirements may not be satisfied even with SL PRS bandwidth of 400 MHz.

From RAN1's perspective, it is recommended that SL PRS bandwidths of up to 100 MHz are supported by the specifications in FR1 spectrum.

NOTE: The above recommendations are based on the evaluations in licensed and ITS spectra.

## 7.3 Sidelink positioning solutions

Sidelink positioning is recommended for normative work, including:

- Sidelink positioning in-coverage, partial coverage and out-of-coverage scenarios may be supported.

- How to enable the procedures/signaling for supporting SL positioning in in-coverage, partial coverage and out-of-coverage scenarios will be further discussed in normative work.

- Protocols between UE and UE

- RAN2 will enable the support of SL PRS configuration in normative work based on the progress in RAN1.

- RAN2 will design protocol and procedures for SL positioning between UEs (SLPP) in normative work.

- Protocols between LMF and UE

- RAN2 will discuss the details of functionalities of LMF for supporting SL positioning in normative work.

- RAN2 will discuss the protocol details to support sidelink positioning procedures between UE and LMF in normative work.

For the solutions for sidelink positioning,

- The following two operation scenarios are recommended for normative work:

- Operation Scenario 1: PC5-only-based positioning.

- Operation Scenario 2: Combination of Uu- and PC5-based positioning.

- RTT-type solution(s) using SL, SL-AoA, and SL-TDOA are recommended for normative work.

- Both single-sided and double-sided RTT methods, striving to minimize the changes needed on top of the specification support for single-sided RTT, if any, for the introduction of double-sided RTT.

- For SL-TDOA, DL-TDOA-like operation and UL-TDOA-like operation is recommended for normative work.

- For the support of the above methods the following measurements are recommended for normative work:

- SL PRS based Rx-Tx measurement

- SL PRS based RSTD measurement

- SL PRS based RSRP measurement

- SL PRS based RSRPP measurement

- SL PRS based RTOA measurement

- SL PRS based Azimuth of Arrival (AoA) and SL Zenith of Arrival (ZoA) measurement.

- A new sidelink reference signal (SL PRS) is recommended for normative work.

- Such a reference signal should use a comb-based frequency domain structure and a pseudorandom-based sequence where the existing sequence of DL-PRS should be used as a starting point.

- SCI can be used for reserving/indicating one or more SL PRS resources.

- Both a resource allocation Scheme 1 and Scheme 2 is recommended for normative work, where Scheme 1 corresponds to a network-centric operation SL PRS resource allocation and Scheme 2 corresponds to UE autonomous SL PRS resource allocation.

- For resource allocation mechanism for SL PRS in Scheme 2, a sensing-based resource allocation, or a random resource selection, or both, should be introduced, where the legacy designs for UE autonomous resource allocation are used as a starting point.

- With regards to the SL PRS transmission, both dedicated resource pool and shared resource pool with Rel-16/Rel-17/Rel-18 SL communication are recommended for normative work.

- For SL Positioning resource (pre-)configuration in a shared resource pool with Rel-16/17/18 sidelink communication, backward compatibility with legacy Rel-16/17 UEs should be ensured.

- With regards to the power control for SL PRS at least Open Loop Power Control (OLPC) is recommended for normative work.

- Unicast, Groupcast (not including many to one) and Broadcast of SL PRS transmission are recommended for normative work.

## 7.4 Integrity for RAT-dependent positioning techniques

Both UE-based and LMF-based integrity for RAT-Dependent Positioning Techniques are recommended for normative work.

## 7.5 PRS/SRS bandwidth aggregation

Conclusions on support of PRS/SRS bandwidth aggregation from the studies performed in RAN1 can be found in [2].

As part of the current study, PRS/SRS bandwidth aggregation for intra-band contiguous carriers is studied by RAN4. Based on the study, PRS/SRS bandwidth aggregation for intra-band contiguous carriers is concluded as feasible for single chain Tx/Rx architectures at both the UE and gNB.

The assumption for a single-chain Tx architecture is that PRS/SRS resources to be aggregated are transmitted from a single Tx antenna.

PRS/SRS bandwidth aggregation across PFLs for positioning measurements is concluded as feasible from RRM perspective.

## 7.6 NR carrier phase positioning

Based on the study, it is concluded that it is feasible to use existing DL PRS and SRS signals to obtain the carrier phase measurements for achieving a horizontal accuracy of up to a few centimeters at least at 50% under certain conditions, including the PRU(s) being located in LOS with TRP(s), and the locations of the PRU(s) and TRPs known with centimeter-level accuracy, in the agreed evaluation assumptions.

If NR CPP is introduced,

- Existing DL PRS and UL SRS for positioning purpose are recommended as the reference signals to enable positioning based on NR carrier phase measurements for both UE-based and UE-assisted positioning.

- New measurements are recommended to be introduced for supporting UE-based and UE-assisted NR carrier phase positioning.

- Multipath mitigation methods for the carrier phase positioning are recommended to be introduced during normative work.

## 7.7 Low power high accuracy positioning

The study of Rel-18 LPHAP focused on the evaluation of whether the existing Rel-17 positioning techniques for UEs in RRC\_INACTIVE state can support the battery life and positioning requirements, and on the analysis of potential enhancements to address any limitations for UEs in RRC\_INACTIVE and/or RRC\_IDLE states, as outlined in Clause 6.4.

The target use case for LPHAP is studied and confirmed that the use case 6 defined by SA1 as the single representative use case. The performance requirement of LPHAP use case 6 is defined, including horizontal accuracy, positioning interval, and battery life. It is assumed that the target horizontal positioning accuracy requirement on LPHAP of <1m can be achieved by Rel-16/17 positioning techniques with a positioning bandwidth of at least 100MHz. The main objective of the LPHAP evaluations from the perspective of lower layers is on UE power consumption, as outlined in Clause 6.4.1.

The evaluations on the existing Rel-17 positioning techniques for UEs in RRC\_INACTIVE state show that the target battery life required by LPHAP use case 6 cannot be satisfied for majority of the evaluation scenarios that are examined. Based on the evaluation, it is concluded that enhancements to meet the target battery life in Rel-18 are necessary.

The following enhancements for LPHAP are recommended for normative work:

- For UL and DL+UL positioning for UEs in RRC\_INACTIVE state, the enhancements on SRS for positioning in order to avoid frequent RRC connection for SRS (re)configuration is recommended for normative work.

- Extending DRX cycle beyond 10.24s was studied and found beneficial towards meeting the battery life requirement for LPHAP and is recommended for normative work on Rel-18 positioning enhancements from physical layer's perspective.

- From physical layer's perspective, DL PRS measurement for UEs in RRC\_IDLE state is recommended for the normative work.

Enhancements on simplified DL PRS configuration with 1-symbol PRS can be studied further and if needed, specified during normative phase.

From RAN2's perspective, LPHAP is recommended for normative work, including:

- Enhancements on SRS configuration

- SRS positioning validity area for UL positioning in RRC\_INACTIVE is recommended for normative work from RAN2's perspective if feasible from RAN1's perspective.

- SRS configuration request is recommended for normative work from RAN2's perspective.

- Pre-configuration of multiple SRS configurations (e.g., for multiple SRS positioning validity areas) is feasible from RAN2's perspective and recommended for normative work.

- Alignment between DRX and PRS is recommended for normative work.

- DL positioning in RRC\_IDLE is recommended for normative work.

- Skipping paging reception in RRC\_INACTIVE is recommended for normative work for achieving LPHAP requirements, if feasible and beneficial from RAN1's perspective.

## 7.8 Positioning of UEs with reduced capabilities

From RAN1's perspective, for positioning of RedCap UEs, support of PRS frequency hopping and SRS frequency hopping are recommended for normative work.

- During the normative work, the complexity of the corresponding capabilities for RedCap UEs should be addressed for the introduction of appropriate capabilities for RedCap UEs.

Annex A:  
Evaluation methodologies

# A.1 Evaluation methodology for sidelink positioning

In this clause, the evaluation methodology and assumptions for evaluation of sidelink positioning methods are described.

Table A.1-1 lists the performance metrics for evaluation of sidelink positioning.

Table A.1-1: Performance metrics for evaluations of sidelink positioning

| Evaluation case | Metrics |
| --- | --- |
| Relative or absolute positioning | - Horizontal accuracy  - Vertical accuracy |
| Ranging | - Ranging distance  - Ranging angle/direction |
| Metrics to be reported | - The percentiles of positioning/ranging accuracy error including 50%, 67%, 80%, 90% of UEs.  - CDF of positioning/ranging accuracy error  - For evaluated methods, sources are expected to report:  - whether the requirements are satisfied, and  - %-ile of UEs satisfying the target positioning accuracy for a requirement that may not be satisfied for 90% of the UEs. |
| Other metrics | Performance metrics other than positioning accuracy, such as PHY/end-to-end latency, are up to companies |

Tables A.1-2 through A.1-6 list the assumptions relevant to evaluation of all use-cases and those specific to each of the identified use-cases of V2X, public safety, commercial, and IIoT, respectively.

Table A.1-2: Evaluation assumptions common to all evaluations of sidelink positioning

| Assumptions | Value |
| --- | --- |
| Simulation bandwidth | - FR1: 10, 20, 40 and 100 MHz  - FR2: 100, 200 and 400MHz |
| Reference signals for sidelink positioning | - Baseline: Existing pattern and sequence of DL-PRS or positioning SRS  - Other choices of pattern and sequence not precluded – companies to provide details.  - AGC settling time is considered. |
| PHY/link level abstraction | Explicit simulation of all links, individual parameters estimation is applied. Companies to provide description of applied algorithms for estimation of signal location parameters. |
| Network and anchor UE synchronization | - Baseline: Perfect synchronization between network and anchor UEs in the evaluation is assumed.  - Network synchronization error and timing errors defined in Table 6-1 in TR 38.857 [2] can also be optionally used for synchronization between BS and BS, between BS and anchor UEs, and between anchor UEs. |
| Sidelink anchor nodes | - For evaluation of SL only positioning, anchor UEs are used to locate target UEs.  - For evaluation of Joint Uu/SL positioning, both BS and anchor UEs are used to locate target UEs.  - Baseline for absolute positioning: sidelink anchors location coordinates are perfectly known.  - Uncertainty in the sidelink anchors’ location coordinates can be considered by companies |
| UE-pair selection for ranging | Relative positioning or ranging is performed between two UEs within X m. Value(s) of X to be reported by companies. |
| Positioning method | To be reported by companies. |
| Additional considerations | - Companies should report whether SL PRS and other SL signals are FDM-ed or not FDM-ed, and whether other SL signals are present.  - System level simulations (rather than link level simulations) are used as the baseline tool.  - For SL positioning evaluation in highway scenario or urban grid scenarios, performance metrics can include absolute horizontal accuracy, relative horizontal accuracy, ranging with distance accuracy, and ranging with direction accuracy (optionally).  - In highway and urban grid scenarios, other UE types, e.g., pedestrian UE or VRU devices may be further considered. |

Table A.1-3: Evaluation assumptions for evaluations of sidelink positioning for V2X use-cases

| Assumptions | Value | |
| --- | --- | --- |
| Scenarios | V2X use-cases with highway and urban grid scenarios defined in TR 37.885 [8].  - Road configuration for urban grid and highway provided in Annex A in TR 37.885 [8] is reused. | |
|  | **Urban grid for V2X** | **Highway for V2X** |
| Carrier frequency | Uu: 4 GHz  SL: 6 GHz | Uu: 2 GHz or 4GHz SL: 6 GHz |
| Deployment layout for absolute positioning | - Alt 1 as optional: BS and UE-type RSU deployment follows TR 36.885, where wrap around method of 19\*3 hexagonal cells with 500m ISD in Figure A.1.3-3 of clause A.1.3 in TR 36.885 [9] is used.  - Alt 2 as baseline: BSs are disabled, UE-type RSUs are uniformly located with 200m spacing on both sides of highway symmetrically.  - Optional: staggered/unsymmetrical UE-type RSU distribution like    NOTE: Alt 1 is assumed for evaluation of joint Uu/PC5 positioning, Alt 2 is assumed for evaluation of PC5-only positioning. | BS and UE-type RSU deployment follows the description in clause A.1.3 in TR 36.885 [9].  - Companies can provide results for additional BS/ UE-type RSU deployments, e.g., additional UE-type RSUs are added to UE-type RSU deployment in TR 36.885 [9]. |
| Deployment layout for relative positioning/ranging | - BSs are disabled  - UE type RSU may be disabled (as baseline) or enabled (as optional)  - If enabled, UE-type RSUs are uniformly located with 200m spacing on both sides of highway symmetrically.  - Optional: staggered/unsymmetrical UE-type RSU distribution like | - BSs are disabled (baseline), or enabled (optional)  - Companies to report their assumptions  - UE type RSU may be disabled or enabled (companies should report their assumption)  - If enabled, UE type RSU deployment follows the description clause A.1.3 in TR 36.885 [9].  - If enabled, companies can provide additional RSU deployment, e.g., additional RSUs are added to RSU deployment in TR 36.885 [9]. |
| BS Tx power | Macro BS: 49dBm | |
| UE Tx power | Vehicle UE or UE type RSU: 23dBm | |
| BS receiver noise figure | 5dB | |
| UE receiver noise figure | 9 dB | |
| UE dropping | UE dropping option A defined in clause 6.1.2 of TR 37.885 [8]:  - UE dropping option A is used for the highway scenario:  - Vehicle type distribution: 100% vehicle type 2.  - Clustered dropping is not used.  - Vehicle speed is 140 km/h in all the lanes as baseline and 70 km/h in all the lanes optionally.  - UE dropping option A is used for the urban grid scenario:  - Vehicle type distribution: 100% vehicle type 2.  - Clustered dropping is not used.  - Vehicle speed is 60 km/h in all the lanes.  In the intersection, a UE goes straight, turns left, turns right with the probability of 0.5, 0.25, 0.25, respectively. | |
| UE antenna model | Description in clause 6.1.4 in TR 37.885 [8] is reused:  - Vehicle UE option 1 is the baseline (Vehicle UE antenna is modelled in Table 6.1.4-8 and 6.1.4-9 in TR 37.885 [8])  - Vehicle UE option 2 (two panels) can be optionally selected by companies. | |
| Channel model | Description in clause 6.2 in TR 37.885 is reused. | |

Table A.1-4: Evaluation assumptions for evaluations of sidelink positioning for public safety use-cases

| Assumptions | Value |
| --- | --- |
| Overall assumptions | Companies to provide detailed simulation assumptions including selected scenarios, channel models, center frequency, UE drop models, etc. |
| Channel model | Channel model in TR 36.843 is reused:  - Reuse the parameters of "Channel models" specified in Clause A.2.1.2 of TR 36.843 with following modification: Each component of channel model reuses what is specified in TR 38.901. |
| Anchor UE height | To be reported by companies, e.g., same as TRP height. |
| Performance metrics | At least include absolute positioning accuracy and ranging with distance accuracy.  - Optional: Relative positioning accuracy or ranging with angle/direction accuracy. |

Table A.1-5: Evaluation assumptions for evaluations of sidelink positioning for commercial use-cases

| Assumptions | Value |
| --- | --- |
| Overall assumptions | Companies to provide detailed simulation assumptions including selected scenarios, channel models, center frequency, UE drop models, etc. |
| Channel model | Channel model in TR 36.843 is reused:  Reuse the parameters of "Channel models" specified in Clause A.2.1.2 of TR 36.843 with following modification: Each component of channel model reuses what is specified in TR 38.901. |
| Anchor UE height | To be reported by companies, e.g., same as TRP height. |
| Performance metrics | At least include absolute positioning accuracy and ranging with distance accuracy.  Optional: Relative positioning accuracy or ranging with angle/direction accuracy. |

Table A.1-6: Evaluation assumptions for evaluations of sidelink positioning for IIoT use-cases

| Assumptions | Value |
| --- | --- |
| Deployment scenario and BS-to-UE channel models | InF-SH and/or InF-DH defined in TR 38.857 [2]. |
| UE-to-UE channel model | - Option 1: BS-to-UE channel model defined in TR 38.901 [11] is revised:  - The UE parameters in the channel model defined in 38.901 [11], e.g., UE height, antenna model, transmit power are used to replace corresponding parameters for BS.  - Anchor UE height to be reported by companies, e.g., anchor UE height is the same as TRP.  - Option 2: D2D channel mode from 36.843 A.2.1.2 is used. |
| Anchor UE dropping | Companies to report how to drop anchor UEs and how to select anchor UEs. |
| Performance metrics | At least include absolute and relative positioning accuracy. |

# A.2 Void

# A.3 Evaluation methodology for NR carrier phase positioning

For evaluations of NR carrier phase positioning, the relevant evaluation assumptions as in TR 38.855 [12] and TR 38.857 [2] are reused, with optional modifications to the assumptions based on appropriate justification.

Evaluations for FR1 bands are considered as baseline while those for FR2 bands are optional.

For modelling of error sources, the following may be considered:

- Phase noise (FR2)

- CFO/Doppler

- Oscillator-drift

- Transmitter/receiver antenna reference point location errors

- Transmitter/receiver initial phase error

- Phase center offset

NOTE: Other error sources are not precluded

NOTE: UE mobility can be considered in the evaluations

NOTE: one or more error sources can be evaluated jointly

NOTE: companies should provide the error sources model with their evaluations

The impact of multipath will be considered as part of evaluations of NR carrier phase positioning, and the methods of mitigating the impact of multipath for the carrier phase positioning will be studied, if it is considered necessary after the evaluation.

The following multipath mitigation methods for the carrier phase positioning, which include, but are not limited to, the following are to be evaluated:

- The methods of estimating the carrier phase of the first path

- NOTE: Both time-domain and frequency-domain methods can be considered

- LOS/NLOS/ Multi-path indication for the carrier phase measurements for improving the accuracy of the position calculation

- Rel-17 LOS/NLOS indicator can be used as the starting point

- Measurements of the first path and additional paths

- E.g., carrier phase measurements, timing measurements

- Other channel information, such as RSRP/RSRPP, CIR/CFR, etc.

Further, the use of PRUs to facilitate NR carrier phase positioning can be evaluated.

Table A.3-1 provides the assumptions for the evaluation of NR carrier phase positioning.

Table A.3-1: Assumptions for evaluation of NR carrier phase positioning

| Assumptions | Value | |
| --- | --- | --- |
| Scenarios | - Baseline: InF-SH, InF-DH  - Optional: Indoor Open Office, UMi, Highway scenarios  - Other evaluation scenarios are not precluded  - Existing Rel-17 DL/UL reference signals for the Uu interface are to be used for the Highway scenario. | |
| Frequency errors – NOTE 1 | **Ideal** | **Practical** |
| Initial residual CFO  (is the same for one measurement instances [or multiple phase measurement instances]) | 0 (UE/TRP) | Uniform distribution within:  - [-30, +30] Hz (FR1, UE), [-100, +100] Hz (FR1, UE),  - [-120, +120] Hz (FR2, UE), [-400, +400] Hz (FR2, UE),  - [-10, +10] Hz (for each TRP, FR1),  - [-40, +40] Hz (for each TRP, FR2). |
| Oscillator-drift  (is the same for one or multiple phase measurement instances for positioning fix) | 0 (UE/TRP) | Uniform distribution within:  - [-0.1, 0.1] ppm (UE)  - [-0.02, +0.02] ppm (each TRP) within measurement duration |
| Antenna reference point (ARP) location error of a TRP | No ARP error | A zero-mean, truncated Gaussian distribution with zero mean and standard deviation of T=[1, 5] cm truncated to 2T in each of (x, y, z) direction |
| Initial phase of a transmitter | Modelled as a random variable uniformly distributed within [0, 2pi]  - The initial phase of a transmitter applies to all subcarriers of the same carrier frequency associated with the transmitter. The initial phases of a transmitter for different carriers can be assumed to be independent of each other. | |
| Initial phase of a receiver | Modelled as a random variable uniformly distributed within [0, 2pi]  - The initial phase of a receiver applies to all subcarriers of the same carrier frequency associated with the receiver  - The initial phases of a receiver for different carriers can be assumed to be independent of each other. | |
| UE/TRP antenna Phase Center Offset (PCO) | *dPCO = a \* dPhi + w,*  where  - *a* is the scale factor, *a*=[0, 1, 3]  - *dPhi* is the direction difference (in degrees):  - Example 1: *dPhi* is the difference between the true and the calculated (or measured) directions between a transmitter (UE/TRP) and a receiver (TRP/UE).  - Example 2: *dPhi* is the direction difference between one UE to two TRPs, or between one TRP to two UEs.  - NOTE: Example 1 may be more suitable for modelling the residual PCO of a calibrated antenna; while Example 2 may be more suitable for modelling the PCO of an uncalibrated antenna (see [91]).  - *w* is 0 or a random variable uniformly distributed within [-2, +2], or [-5, +5], or [-X, +X] degrees  - Value of X is left up to companies  - NOTE: the above model is valid only when absolute value of *dPhi* < Y degrees  - Value of Y is left up to companies | |
| Time instances for carrier phase measurements | UE position can be calculated by the use of carrier phase measurements obtained at the *M* sequential time instances, where  - Baseline:  - M=1  - Optional:  - M=4  - Other values of M  - Companies should report their assumptions on UE mobility (e.g., speed) | |
| NOTE 1: The Doppler frequency can be determined based on the UE speed in the evaluation assumption. | | |

# A.4 Evaluation methodology for low power high accuracy positioning

Table A.4-1 lists the common assumptions for evaluation of LPHAP.

Table A.4-1: Evaluation assumptions common to all evaluations of LPHAP

| Assumptions | Value |
| --- | --- |
| Frequency range | FR1 baseline; FR2 optional |
| SCS | 30kHz for FR1 (baseline); 120kHz for FR2 (optional) |
| Bandwidth of the DL PRS and UL SRS for positioning | 100 MHz |
| Measurements per position fix | Single-sample measurement per position fix (baseline); 4-sample measurement per position fix (optional) |
| UE mobility | Up to 3 km/h |
| Power consumption modelling – basic considerations | - Power consumption of 5GC data traffic is not modelled and only the power consumption of the traffic type related to LPHAP positioning (e.g., obtaining/updating SRS configurations, DL PRS measurement reporting, etc.) is considered.  - Consideration of power consumption due to paging monitoring is not precluded for baseline evaluation.  - Up to each company to provide detailed power model and evaluation results on power consumption in FR2.  - Adopt the power consumption model, additional transition energy and total transition time of the three sleep types (deep sleep, light sleep, and micro sleep) in TR38.840 [13] as the evaluation baseline. |
| Periodicity of DL PRS / UL SRS for positioning | Baseline: 1 DL PRS / UL SRS for positioning occasion per N I-DRX cycle(s)  - Candidate values of N to evaluate is 1 and 8 for I-DRX cycle of 1.28s.  - Up to companies to select one or both of the above values.  - Candidate value of N to evaluate is 1 for I-DRX cycle of 10.24s. |
| I-DRX configuration | Included in the baseline evaluations  - I-DRX cycles: 1.28s (baseline); 10.24s (optional)  - NOTE: This does not preclude the case where no I-DRX cycle nor paging is considered in the evaluation of potential solutions to maximize the battery life. |
| e-DRX and/or paging reception | The following may be optionally considered:  - e-DRX cycles to evaluate: 20.48s; 30.72s.  - For paging reception:  - 1 paging occasion is included in one eDRX cycle  - 10% paging rate  - No paging reception can be optionally evaluated.  - 1 DL PRS and/or UL SRS for positioning occasion per 1 eDRX cycle  - Minimizing the gap between PRS measurement, SRS transmission and/or measurement reporting with paging monitoring in time domain can be evaluated. |
| Positioning Reference Signal Bandwidth assumption | At least when the positioning accuracy is evaluated without jointly evaluating the associated power consumption, the target horizontal positioning accuracy requirement on LPHAP of <1m is assumed to be achieved by Rel-16/17 positioning techniques with a positioning bandwidth of at least 100 MHz. |

For conversion between relative power unit and device battery lifetime to identify any performance gaps, the following characterization is considered:

- Battery life is used as the metric to identify the gap

in which,

- C1 is the battery capacity of the reference device

- T1 is the battery life of the reference device

- P1 = 50 is the relative power unit obtained based on the reference traffic type

- X is the percentage of the power consumed by the reference traffic type

- C2 is the battery capacity of the LPHAP device

- P2 is the evaluated relative power unit of the LPHAP device

- T2\_req is the target battery life of the LPHAP device

- K is an implementation factor, K = 1 (baseline); K = 0.5, 2, 4 (optional)

NOTE: In the above model, the voltage is assumed to be the same for the reference device and the LPHAP device.

NOTE: As the reference device and LPHAP device characteristics, and therefore the parameter values of the model for determining battery life, is dependent on implementation factors, manufacturer, design options and cost options, it is up to individual company to evaluate the optional K values, and report the corresponding parameter values.

Examples of these parameters are provided as in Table A.4-2.

Table A.4-2: Example values of parameters for conversion between power consumption unit and device battery lifetime

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| C1 (mAh) | T1 (hours) | X | Reference traffic type | C2 (mAh) | T2req (months) |
| 4500 | 12 | 20 % | FTP (model 3) | 800 for Type A LPHAP device (baseline)  4500 for Type B LPHAP device (optional) | 6 to 12 |

The power consumption model used for baseline evaluation of Rel-17 positioning in RRC\_INACTIVE state is as in Table A.4-3.

Table A.4-3: Power consumption model for baseline evaluation of Rel-17 positioning in RRC\_INACTIVE state

|  |  |
| --- | --- |
| Power State | Relative power |
| PDCCH-only (PPDCCH) | 50NOTE |
| PDCCH + PDSCH (PPDCCH+PDSCH) | 120 |
| SSB proc. (PSSB) | 50 |
| UL | 250 (0 dBm)  700 (23 dBm) |
| (Optional) PRACH | 210 |
| (Optional) BWP switching | 50 |
| (Optional) Intra-frequency RRM measurement (Pintra) | 60 (synchronous case, N=8, measurement only; Pintra, meas-only)  80 (combined search and measurement; Pintra, search+meas) |
| (Optional) Inter-frequency RRM measurement (Pinter) | 60 (measurement only per freq. layer; Pinter, meas-only)  150 (neighbor cell search power per freq. layer; Pinter, search-only)  Micro sleep power assumed for switch in/out a freq. layer |
| NOTE: Power scaling to 20MHz reception bandwidth follows the rule in Clause 8.1.3 of TR 38.840, i.e., max {reference power \* 0.4, 50}. | |

For the purpose of LPHAP evaluation, an ultra-deep sleep state is considered with the two modelling options as in Table A.4-4.

Table A.4-4: Power consumption model for ultra-deep sleep state

|  |  |
| --- | --- |
| Parameters | Values |
| Model A (NOTE 1): | |
| Relative power unit | 0.015 |
| Additional transition energy | 10000 (NOTE 2) |
| Total transition time | 400 ms |
| Model B (NOTE 1, NOTE 3): | |
| Relative power unit | 0.01 |
| Additional transition energy | 480 |
| Total transition time | 25 ms |
| Restrictions in processing associated with Model B after the UE comes out of ultra-deep sleep state can be considered further. | |
| NOTE 1: No new device type is expected based on ultra-deep sleep power modelling.  NOTE 2: Power consumption analysis from individual companies with additional transition energy of 5000 can be optionally evaluated.  NOTE 3: Power consumption analysis from individual companies with Model B can be optionally evaluated. | |

For DL PRS-based positioning, the following reference configuration is assumed:

- Number of Positioning Frequency Layers = 1;

- Number of DL PRS resources measured per slot = 8;

- DL PRS instance of smaller than or equal to 1 slot duration.

The power consumption model for DL PRS-based positioning and UL SRS-based positioning are as in Tables A.4-4 and A.4-5 respectively.

Table A.4-5: Power consumption model for DL PRS-based positioning

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **N: Number of** **TRPs for DL PRS measurement** | **Synchronous case (baseline)** | | **Asynchronous case (optional)** | |
| **FR1 (baseline)** | **FR2**  **(optional)** | **FR1** | **FR2** |
| N=4 (baseline) | 120 | 195 | 140 | 255 |
| N=8 (optional) | 150 | 225 | 170 | 285 |

Table A.4-6: Power consumption model for UL SRS-based positioning

|  |  |
| --- | --- |
| **Power State** | **Relative power** |
| SRS | 210 (baseline);  700 (optional) |

For DL positioning, at least the following power components and parameter values are considered for the baseline evaluation of Rel-17 RRC\_INACTIVE positioning:

- For UE-assisted DL positioning,

- SSB proc. with 2 ms duration and the periodicity of I-DRX cycle;

- Paging with 2 ms duration, the periodicity of I-DRX cycle, and group paging rate of 10%;

- DL PRS measurement with 0.5 ms duration;

- CG-SDT with 1ms duration and the periodicity of positioning interval;

- RRCRelsease after the CG-SDT can be optionally included with [1] ms duration;

- (Optional) BWP switching with [1] ms duration;

- (Optional) Intra-/inter-frequency RRM measurement in low SINR condition with [1] ms duration;

- (Optional) RA-SDT (e.g., including CORSET0 + SIB1, PRACH, RAR, Msg 3/4/5) in case of CG-SDT is unavailable.

- For UE-based DL positioning,

- SSB proc. with 2 ms duration and the periodicity of I-DRX cycle;

- Paging with 2 ms duration, the periodicity of I-DRX cycle, and group paging rate of 10%;

- DL PRS measurement with 0.5 ms duration;

- (Optional) BWP switching with [1] ms duration;

- (Optional) Intra-/inter-frequency RRM measurement in low SINR condition with [1] ms duration.

For UL positioning, at least the following power components and parameter values are considered for the baseline evaluation of Rel-17 RRC\_INACTIVE positioning:

- SSB proc. with 2 ms duration and the periodicity of I-DRX cycle;

- Paging with 2 ms duration, the periodicity of I-DRX cycle, and group paging rate of 10%;

- UL SRS for positioning transmission with 0.5 ms duration;

- (Optional) BWP switching with [1] ms duration;

- (Optional) Intra-/inter-frequency RRM measurement in low SINR condition with [1] ms duration.

In addition to the above, the following should be noted for DL and UL positioning in modelling the power components and timelines:

- The power component and parameter values for DL and UL positioning are respectively applicable to the DL and UL parts of UE-assisted DL+UL positioning method.

- Additional power components and different parameter values for those in brackets above can be considered in the evaluation.

- Companies are encouraged to provide the assumption on the timeline between different power consumption events in the evaluation of potential enhancements to reduce the transition times between different power states and to extend the sleeping time as much as possible.

# A.5 Evaluation methodology for positioning for RedCap UEs

In this clause, the evaluation methodology and assumptions for evaluation of positioning performance for Reduced Capability (RedCap) NR UEs are described.

For evaluation of RedCap UE positioning performances, all RAT based positioning methods can be considered. Sources should detail the chosen method(s) when presenting performance evaluations.

Table A.5-1 lists the set of common parameters applicable for evaluation of positioning performance of RedCap UEs.

Table A.5-1: Common parameters applicable for all scenarios for Redcap UEs evaluations

| Assumptions | FR1 Specific Values | FR2 Specific Values |
| --- | --- | --- |
| Carrier frequency, GHz | 3.5GHz, 700MHz (optional) – NOTE 1 | 28GHz – NOTE 1 |
| Bandwidth, MHz | 20MHz baseline, 5MHz optional | 100MHz |
| Subcarrier spacing, kHz | 30KHz, 15KHz (for 700MHz carriers) | 120kHz |
| Positioning Reference Signals | DL PRS and/or UL SRS.  Sources to detail the chosen configuration of reference signal(s) | |
| Deployment scenarios | - Baseline: (Case 1): UMi street canyon, as described in Table 6.1-1-4 of TR 38.855  - Optional outdoor:  - (Case 2): UMa, as described in Table 6.1-1-6 of TR 38.855  - (Case 3): RMa, companies to report parameters assumed for evaluations.  - Baseline (Case 4): InF-SH as described in Table 6.1-1 of TR 38.857  - Optional indoor (Case 5): Indoor Open Office, as described in Table 6.1-1-3 of TR 38.855  - Optional indoor (Case 6): InF-DH as described in Table 6.1-1 of TR 38.857 | |
| **gNB model parameters** |  |  |
| gNB noise figure, dB | 5dB | 7dB |
| gNB antenna configuration | At 700MHz:  (M,N,P,Mg,Ng) = (4,2,2,1,1), (dH, dV) = (0.5, 0.8)λ – NOTE 3 | |
| **UE model parameters** |  |  |
| UE noise figure, dB | 9dB – NOTE 1 | 13dB – NOTE 1 |
| UE max. TX power, dBm | 23dBm – NOTE 1 | 23dBm – NOTE 1  EIRP should not exceed 43 dBm. |
| UE antenna radiation pattern | Omni, 0dBi | Antenna model according to Table 6.1.1-2 in TR 38.855 |
| UE antenna configuration | Panel model 1 – NOTE 1  dH = 0.5λ, for 1Rx UEs: (M, N, P, Mg, Ng) = (1, 1, 1, 1, 1)  for 2Rx UEs: (M, N, P, Mg, Ng) = (1, 1, 2, 1, 1) | - (M, N, P, Mg, Ng) = (1, 2, 2, 1, 1) **as minimum antenna configuration (baseline)**  - (M, N, P, Mg, Ng) = (2, 2, 2, 1, 1) **as optional configuration.** |
| UE antenna radiation pattern | Omni, 0dBi | Antenna model according to Table 6.1.1-2 in TR 38.855 |
| Number of UE branches | Baseline: 1Rx 1Tx  Optional: 2Rx 1 Tx | Baseline: 2Rx and 1Tx |
| PHY/link level abstraction | Explicit simulation of all links, individual parameters estimation is applied. Companies to provide description of applied algorithms for estimation of signal location parameters. | |
| Network synchronization | The network synchronization error, per UE dropping, is defined as a truncated Gaussian distribution of (T1 ns) rms values between a gNB and a timing reference source which is assumed to have perfect timing, subject to the largest timing difference of T2 ns, where T2 = 2\*T1  - That is, the range of timing errors is [-T2, T2]  - T1: 0ns (perfectly synchronized), 50ns (Optional) | |
| UE/gNB RX and TX timing error | (Optional) The UE/gNB RX and TX timing error, in FR1/FR2, can be modeled as a truncated Gaussian distribution with zero mean and standard deviation of T1 ns, with truncation of the distribution to the [-T2, T2] range, and with T2=2\*T1:  - T1: X ns for gNB and Y ns for UE  - X and Y are up to sources  - NOTE: RX and TX timing errors are generated per panel independently  Apply the timing errors as follows:  - For each UE drop,  - For each panel (in case of multiple panels)  - Draw a random sample for the Tx error according to [-2\*Y,2\*Y] and another random sample for the Rx error according to the same [-2\*Y,2\*Y] distribution.  - For each gNB  - For each panel (in case of multiple panels)  - Draw a random sample for the Tx error according to [-2\*X,2\*X] and another random sample for the Rx error according to the same [-2\*X,2\*X] distribution.  - Any additional Time varying aspects of the timing errors, if simulated, can be left up to each company to report.  - For UE evaluation assumptions in FR2, it is assumed that the UE can receive or transmit at most from one panel at a time with a panel activation delay of 0ms. | |
| Selection of RedCap UEs for indoor scenarios for reporting of results | - (Required): The UEs inside the convex hull of the horizontal BS deployment area.  - (Optional): All the UEs. | |
| For the evaluation of TX/RX frequency hopping for positioning of RedCap UEs, value of time gap between two consecutive hops | Includes at least from 100us to 5ms  - Sources should indicate if other smaller values are used in their evaluations and justify the feasibility of smaller values. | |
| For the evaluation of TX/RX frequency hopping for positioning of RedCap UEs, value of UE speed | 3 km/h, 30 km/h, 60km/h.  - Other values are not precluded. | |
| NOTE 1: According to TR 38.802 [14]  NOTE 2: According to TR 38.901 [11]  NOTE 3: According to TR38.830 [15] | | |

Annex B:  
Evaluation results

# B.1 Evaluation results for sidelink positioning

Please see separate MS Word file for Annexes B.1, B.2, B.3.

# B.2 Evaluation results for integrity for RAT-dependent positioning techniques

Please see separate MS Word file for Annexes B.1, B.2, B.3.

# B.3 Void

# B.4 Evaluation results for NR carrier phase positioning

Please see separate MS Word file for Annex B.4.

# B.5 Evaluation results for low power high accuracy positioning

Please see separate MS Word file for Annex B.5.

# B.6 Evaluation results for positioning for RedCap UEs

Please see separate MS Word file for Annexes B.6 and X.

Annex X:  
Change history

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Change history** | | | | | | | |
| **Date** | **Meeting** | **TDoc** | **CR** | **Rev** | **Cat** | **Subject/Comment** | **New version** |
| 2022-05 | RAN1#109-e | R1-2205398 |  |  |  | Baseline TR skeleton. | 0.0.0 |
| 2022-08 | RAN1#110 | R1-2208275 |  |  |  | Incorporating decisions from RAN1 #109-e and RAN1 #110 | 0.1.0 |
| 2022-10 | RAN1#110bis-e | R1-2210715 |  |  |  | Incorporating decisions from RAN1 #109-e, RAN1 #110, and RAN1 #110bis-e | 0.2.0 |
| 2022-11 | RAN1#111, RAN2#120, RAN3#118, RAN4#105 | R1-2213017 |  |  |  | Revised from RAN1#110bis-e version (not endorsed by RAN1) and includes and incorporating decisions from RAN1 #111, RAN2 #120, RAN3 #118, and RAN4 #105. | 0.2.0 |
| 2022-12 | RAN #98e | RP-223289 |  |  |  | v1.0.0, based on RAN1-endorsed v0.2.0, submitted to RAN #98e for approval | 1.0.0 |
| 2022-12 | RAN #98e |  |  |  |  | TR under change control further to the approval for inclusion in Rel-18 by RAN | 18.0.0 |