

3GPP TR 38.857 V1.1.0 (2021-03)

Technical Report

3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Study on NR Positioning Enhancements; (Release 17)



The present document has been developed within the 3rd Generation Partnership Project (3GPP™) and may be further elaborated for the purposes of 3GPP. The present document has not been subject to any approval process by the 3GPP Organizational Partners and shall not be implemented. This Specification is provided for future development work within 3GPP only. The Organizational Partners accept no liability for any use of this Specification. Specifications and Reports for implementation of the 3GPP™ system should be obtained via the 3GPP Organizational Partners' Publications Offices.

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>

Copyright Notification

No part may be reproduced except as authorized by written permission.
The copyright and the foregoing restriction extend to reproduction in all media.

© 2020, 3GPP Organizational Partners (ARIB, ATIS, CCSA, ETSI, TSDSI, TTA, TTC).
All rights reserved.

UMTS™ is a Trade Mark of ETSI registered for the benefit of its members
3GPP™ is a Trade Mark of ETSI registered for the benefit of its Members and of the 3GPP Organizational Partners
LTE™ is a Trade Mark of ETSI registered for the benefit of its Members and of the 3GPP Organizational Partners
GSM® and the GSM logo are registered and owned by the GSM Association

Contents

Foreword	5
1 Scope	7
2 References	7
3 Definitions of terms, symbols and abbreviations	9
3.1 Terms	9
3.2 Symbols	10
3.3 Abbreviations	10
4 General description of NR positioning enhancements	11
5 Target requirements for NR positioning enhancements in Rel-17	11
5.1 Target requirements	11
5.2 Performance evaluation metrics	12
5.2.1 Horizontal accuracy	12
5.2.2 Vertical accuracy	12
5.2.3 Other metrics	12
6 Additional scenarios and channel models for NR positioning enhancements	14
6.1 IIoT use cases	17
6.2 General commercial use cases	20
7 Studied NR positioning enhancements	20
8 Performance evaluations for Rel-17 targets	21
8.1 Performance analysis of Rel-16 positioning solutions	21
8.1.1 Positioning accuracy analysis	21
8.1.2 Physical layer latency analysis for Rel-16	44
8.1.3 Higher layer latency analysis for Rel-16	49
8.2 Performance analysis of studied NR positioning enhancements	65
8.2.1 Positioning accuracy analysis for NR positioning enhancements	65
8.2.2 Physical layer latency analysis for NR positioning enhancements	95
8.3 Efficiency analysis for NR positioning enhancements	98
8.3.1 Network efficiency analysis for NR positioning enhancements	98
8.3.2 UE efficiency analysis for NR positioning enhancements	99
8.4 Summary of performance evaluations	102
9 Positioning integrity and reliability	108
9.1.1 Integrity Concepts	108
9.2 Use Cases	112
9.2.1 Automotive	112
9.2.2 Rail	113
9.2.3 Industrial IoT	114
9.2.4 Use Case Summary	114
9.3 Positioning Integrity Error Categories	116
9.3.1 RAT-Independent	116
9.4 Positioning Integrity Methods	119
9.4.1 RAT-Independent	119
10 Identified NR impacts in Rel-17	123
10.1 NR positioning for UEs in RRC_INACTIVE state	123
10.2 On-demand transmission and reception of DL PRS	123
10.3 Aggregation of DL PRS resources	124
10.4 Aggregation of SRS for positioning resources	124
10.5 Enhancements for UE Rx/Tx and gNB Rx/Tx timing delays	124
10.6 Enhancements for angle based methods	124
10.7 Enhancements of information reporting from UE and gNB for supporting multipath/NLOS mitigation	124
10.8 Enhancements of signaling & procedures for reducing NR positioning latency	125
10.9 DL positioning measurement in RRC_IDLE state	125
10.10 Scope of RRC_IDLE/INACTIVE positioning	126

10.10.1 RAT-Independent positioning	126
10.11 Signalling and procedures to support GNSS positioning integrity	126
11 Conclusions	126
B.1 Evaluation of horizontal positioning accuracy with gNB/UE TX/RX timing error	130
B.2 Evaluation of physical layer latency	135
C.1 Performance analysis of Rel-16 positioning solutions	148
C.2 Performance of studied NR positioning enhancements	148
C.3 Efficiency analysis for NR positioning enhancements	148

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:

Version x.y.z

where:

- x the first digit:
 - 1 presented to TSG for information;
 - 2 presented to TSG for approval;
 - 3 or greater indicates TSG approved document under change control.
- 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 NR positioning enhancements" [2]. 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 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] RP-193237: "new SID on NR Positioning Enhancements".
- [3] 3GPP TR 38.855: "Study on NR Positioning (Release 16)".
- [4] R1-2009433 Evaluation results for Rel-16 positioning and Rel-17 enhancement Huawei, HiSilicon
- [5] R1-2007665 Evaluation of NR positioning performance vivo
- [6] R1-2007720 Evaluation of achievable positioning accuracy BUPT
- [7] R1-2007754 Evaluation of achievable accuracy and latency ZTE
- [8] R1-2007859 Discussion of evaluation of NR positioning performance CATT
- [9] R1-2007908 NLOS Identification and Mitigation FUTUREWEI
- [10] R1-2009390 Update of Evaluation Results for NR Positioning Performance in I-IoT Scenarios Intel Corporation
- [11] R1-2007997 NR Positioning Latency Evaluations Lenovo, Motorola Mobility
- [12] R1-2008225 Evaluation of NR positioning in IIOT scenario OPPO
- [13] R1-2009555 Results on evaluation of achievable positioning accuracy and latency Nokia, Nokia Shanghai Bell
- [14] R1-2009502 Discussion on Performance evaluation of Rel-17 positioning Sony
- [15] R1-2008416 Discussions on evaluation of achievable positioning accuracy and latency for NR positioning LG Electronics
- [16] R1-2008489 Evaluation of achievable positioning latency InterDigital, Inc.
- [17] R1-2009708 Evaluation of achievable Positioning Accuracy & Latency Qualcomm Incorporated
- [18] R1-2009428 Evaluation of positioning enhancements Fraunhofer IIS, Fraunhofer HHI
- [19] R1-2008720 Positioning evaluation results on potential enhancements for additional use cases CeWiT

- [20] R1-2008764 Evaluation of achievable positioning accuracy and latency Ericsson
- [21] R1-2008765 Potential positioning enhancements Ericsson
- [22] R1-2007666 Discussion on potential positioning enhancements vivo
- [23] R1-2005380 Evaluation of achievable positioning accuracy and latency vivo
- [24] 3GPP TS 22.261 Service requirements for the 5G system; Stage 1 (Release 17)
- [25] RP-202094 Revised SID: Study on NR Positioning Enhancements CATT, Intel Corporation
- [26] 3GPP TS 38.901 Study on channel model for frequencies from 0.5 to 100 GHz (Release 16)
- [27] 3GPP TS 38.305: "NG Radio Access Network (NG-RAN); Stage 2 functional specification of User Equipment (UE) positioning in NG-RAN".
- [28] EGNOS Open Service (OS) Service Definition Document, European Commission, Version 2.3, 2017.
- [29] 3GPP TS 24.571 Control plane Location Services (LCS) procedures (Release 16)
- [30] 3GPP TR 22.872: "Study on positioning use cases".
- [31] R2-2006541, TP for Study on Positioning Integrity and Reliability, Swift Navigation, Deutsche Telekom, u-blox, Ericsson, Mitsubishi Electric, Intel Corporation, CATT, UIC.
- [32] Zhu, N., Marais, J., Betaille, D., Berbineau, M., "GNSS Position Integrity in Urban Environments: A Review of Literature", IEEE Transactions on Intelligent Transportation Systems, Vol. 19, No. 9, Sep 2018.
- [33] European Space Agency, "Integrity", Navipedia, 2018, <<https://gssc.esa.int/navipedia/index.php/Integrity>>.
- [34] Reid, T., Houts, S., Cammarata, R., Mills, G., Agarwal, S., Vora, A., Pandey, G., "Localization Requirements for Autonomous Vehicles," SAE International Journal of Connected and Automated Vehicles, Vol. 2, No. 3, pp. 173–190, Sep 2019.
- [35] GSA-MKD-RD-UREQ-250283, "Report on Road User Needs and Requirements: Outcome of the European GNSS' User Consultation Platform", Issue/Rev: 2.0, 2019.
- [36] GSA-MKD-RL-UREQ-250286, "Report on Rail User Needs and Requirements: Outcome of the European GNSS' User Consultation Platform", Issue/Rev: 2.0, 2019.
- [37] 5GAA, "White Paper – C-V2X Use Cases Methodology, Examples and Service Level Requirements, 2019.
- [38] Global Positioning System Wide Area Augmentation System (WAAS) Performance Standard, Department of Transportation USA, Federal Aviation Authority, Edition 1, October 2008.
- [39] International Civil Aviation Organization, "Annex 10 to the Convention on International Civil Aviation, Aeronautical Telecommunications: International Standards and Recommended Practices", 2006.
- [40] RTCA DO-178C, "Software Considerations in Airborne Systems and Equipment Certification," 2011.
- [41] DO-229D, RTCA, "RTCA DO-229D Minimum Operational Performance Standards for Global Positioning System/Satellite-Based Augmentation System Airborne Equipment," 2013.
- [42] SAE J3016, "Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems", SAE International, 2018.
- [43] European GNSS Agency, "GNSS User Technology Report issue 3", 2020.
- [44] Air Force Research Laboratory, "IS-AGT-100 Chips Message Robust Authentication (Chimera)", 2019.

- [45] 3GPP TR 22.804, “Study on Communication for Automation in Vertical Domains”.
- [46] Working Group C (WG-C), “EU-U.S. Cooperation on Satellite Navigation”, ARAIM Technical Subgroup, Interim Report, Issue 1, December 2012.
- [47] 5G ACIA White Paper, "5G for Automation in Industry: Primary use cases, functions and service requirements", July 2019.
- [48] Elliott D. Kaplan, Christopher J. Hegarty, “Understanding GPS/GNSS Principles and Applications” Third Edition, Artech House, 2017.
- [49] R2-2010075, Methodologies for network-assisted and UE-assisted integrity, Ericsson.
- [50] R2-2006674, Discussion on error sources, threat models, occurrence rates and failure modes, CATT.
- [51] R2-2101391, GNSS Integrity Methodologies, Ericsson.
- [52] R2-2009282, Error sources, threat models, occurrence rates, and failure modes, Fraunhofer IIS, Fraunhofer HHI.
- [53] R2-2101437, Text Proposal to methodologies for GNSS position integrity, ESA.

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].

Positioning Integrity: A measure of the trust in the accuracy of the position-related data provided by the positioning system and the ability to provide timely and valid warnings to the LCS client when the positioning system does not fulfil the condition for intended operation.

Integrity Availability: The integrity availability is the percentage of time that the PL is below the required AL.

Feared Event: Feared Events are considered to be all possible events (e.g., of natural, man-made, systemic or operational nature) that can cause the computed position to deviate from the true position, regardless of whether a specific fault can be identified in one of the positioning systems or not.

Target Integrity Risk (TIR): The probability that the positioning error exceeds the Alert Limit (AL) without warning the user within the required Time-to-Alert (TTA).

NOTE: The TIR is usually defined as a probability rate per some time unit (e.g., per hour, per second or per independent sample).

Alert Limit (AL): The maximum allowable positioning error such that the positioning system is available for the intended application. If the positioning error is beyond the AL, the positioning system should be declared unavailable for the intended application to prevent loss of positioning integrity.

NOTE: When the AL bounds the positioning error in the horizontal plane or on the vertical axis then it is called Horizontal Alert Limit (HAL) or Vertical Alert Limit (VAL) respectively.

Time-to-Alert (TTA): The maximum allowable elapsed time from when the positioning error exceeds the Alert Limit (AL) until the function providing positioning integrity announces a corresponding alert.

Misleading Information (MI): An MI event occurs when, the positioning system being declared available, the positioning error exceeds the PL.

Hazardous Misleading Information (HMI): An HMI event occurs when, the positioning system being declared available, the positioning error exceeds the AL without announcing an alert within the TTA.

Integrity Event: An Integrity Event occurs when the positioning system outputs HMI.

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] 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].

AoA	Angle of Arrival
AL	Alert Limit
DL-AoD	Downlink Angle-of-Departure
DL-PRS	Downlink Positioning Reference Signal
DL-TDOA	Downlink Time Difference of Arrival
E-CID	Enhanced Cell-ID
HAL	Horizontal Alert Limit
HMI	Hazardously Misleading Information
HPL	Horizontal Protection Level
LCS	LoCation Services
LMF	Location Management Function
LPP	LTE Positioning Protocol
MI	Misleading Information
MO-LR	Mobile Originated Location Request
MT-LR	Mobile Terminated Location Request
Multi-RTT	Multi-Round Trip Time
NRPPa	NR Positioning Protocol A
PE	Positioning Error
PL	Protection Level
PRS	Positioning Reference Signal
RSRP	Reference Signal Received Power
RSTD	Reference Signal Time Difference
SRS	Sounding Reference Signal
TIR	Target Integrity Risk
TTA	Time-to-Alert
TRP	Transmission-Reception Point
UL-AoA	Uplink Angle of Arrival

UL-RTOA	Uplink Relative Time of Arrival
UL-TDOA	Uplink Time Difference of Arrival
VAL	Vertical Alert Limit
VPL	Vertical Protection Level

4 General description of NR positioning enhancements

3GPP NR radio-technology is uniquely positioned to provide added value in terms of enhanced location capabilities. The operation in low and high frequency bands (i.e. below and above 6GHz) and utilization of massive antenna arrays provides additional degrees of freedom to substantially improve the positioning accuracy. The possibility to use wide signal bandwidth in low and especially in high bands brings new performance bounds for user location for well-known positioning techniques, utilizing timing measurements to locate UE. The recent advances in massive antenna systems can provide additional degrees of freedom to enable more accurate user location by exploiting spatial and angular domains of propagation channel in combination with time measurements.

3GPP Rel-16 has specified various location technologies to support regulatory as well as commercial use cases. The target horizontal positioning requirements for commercial use cases studied in Rel-16 were <3 m (80%) for indoor scenarios and <10 m (80%) for outdoor scenarios (TR 38.855[3]). The 5G service requirements specified in TS 22.261 [24] include High Accuracy Positioning requirements, which are characterized by ambitious system requirements for positioning accuracy in many verticals. For example, on the factory floor, it is important to locate assets and moving objects such as forklifts, or parts to be assembled. Similar needs exist in transportation and logistics, for example.

To address the higher accuracy location requirements resulting from new applications and industry verticals for 5G, a Rel-17 Study Item of "Study on NR Positioning Enhancements" was approved by TSG RAN [2][25]. The study item covers the enhancements and solutions necessary to support the high accuracy (horizontal and vertical), low latency, network efficiency (scalability, RS overhead, etc.), and device efficiency (power consumption, complexity, etc.) requirements for commercial use cases (incl. general commercial use cases and specifically IIoT use cases).

This technical report documents the following accomplishments obtained during the study:

- the target performance requirements for RAT dependent solutions for Rel-17 for both general commercial use cases and IIoT use cases;
- the additional scenarios and channel models for evaluating NR positioning enhancements;
- the NR positioning enhancements candidates for improving accuracy, reducing latency, and improving network and device efficiency for Rel-17;
- evaluation of the achievable positioning performance, including the performance analysis of Rel-16 positioning solutions, the performance analysis, the efficiency analysis, and the observations obtained from the investigations for Rel-17 NR positioning enhancements;
- the identified NR impacts for normative work for Rel-17.

5 Target requirements for NR positioning enhancements in Rel-17

5.1 Target requirements

In Rel-17 target positioning requirements for commercial use cases are defined as follows:

- Horizontal position accuracy (< 1 m) for 90% of UEs
- Vertical position accuracy (< 3 m) for 90% of UEs

- End-to-end latency for position estimation of UE (< 100 ms)
- Physical layer latency for position estimation of UE (< 10 ms)

In Rel-17 target positioning requirements for IIoT use cases are defined as follows:

- Horizontal position accuracy (< 0.2 m) for 90% of UEs
- Vertical position accuracy (< 1 m) for 90% of UEs
- End-to-end latency for position estimation of UE (< 100ms, in the order of 10 ms is desired)
- Physical layer latency for position estimation of UE (<10ms)

Note 1: Target positioning requirements may not necessarily be reached for all scenarios and deployments

Note 2: For some scenarios the requirement for Horizontal position accuracy can be relaxed to < 0.5 m in IIoT use cases.

Note 3: All positioning techniques may not achieve the target positioning requirements over all scenarios

5.2 Performance evaluation metrics

For evaluating performance of NR positioning technologies, the following metrics apply. The following percentiles of positioning error are analyzed: 50%, 67%, 80%, 90%.

5.2.1 Horizontal accuracy

Horizontal accuracy is the difference between the calculated horizontal position and the actual horizontal position of a UE.

5.2.2 Vertical accuracy

Vertical accuracy is the difference between the calculated vertical position and the actual vertical position of a UE.

5.2.3 Other metrics

5.2.3.1 Latency

5.2.3.1.1 Physical layer Latency

Latency includes higher layer and physical layer latency. Physical layer latency for DL only, UL only, DL+UL positioning solutions for UE-based and UE-assisted approaches are separately studied

The physical layer latency start- and end-time are defined for each positioning method in table 5.2.3.1-1

Table 5.2.3.1-1: Definition of physical layer latency start- and end-time

Method	Start	End
UE assisted DL-only & DL-ECID & Multi-RTT	Transmission of the PDSCH from the gNB carrying the LPP Request Location Information message	Successful decoding of the PUSCH carrying the LPP Provide Location Information message
UL-only method & UL ECID & Multi-RTT	Reception by the gNB of the NRPPa measurement request message	The transmission by the gNB of the NRPPa measurement response message
UE-based	<ul style="list-style-type: none"> - Alt. 1: transmission of the PUSCH carrying the MG Request from the UE. - Alt. 2: Transmission of the PDSCH from the gNB carrying the LPP message containing the assistance data - Alt. 3: Start of the Reception of DL PRS 	Successful decoding of the PUSCH at gNB carrying the LPP Provide Location Information message if applicable, otherwise Calculation of Location Estimate at the UE

5.2.3.1.2 Higher layer Latency

Higher layer latencies include processing delays of the various involved nodes (UE, gNB, AMF, LMF, etc) and signalling delays between nodes.

The latency assumptions for the various components (UE, gNB, AMF and LMF) used in higher layer latency analysis are defined in table 5.2.3.1.2-1.

Table 5.2.3.1.2-1: Latency Components

Label	Latency [ms]	Description
Processing Latencies		
$T_{UEProc-RRCReconf}$	10	RRC Reconfiguration processing
$T_{UEProc-RRCDLInfo}$	5	RRC DL information transfer
$T_{UEProc-RRCULInfo}$	2-5	RRC UL information transfer
$T_{UEProc-RRCLocationMeas}$	2-5	RRC Location Measurement Indication
$T_{UEProc-LPPCapab}$	10-20	LPP Provide Capabilities
$T_{UEProc-LPPAssi}$	10	LPP Provide Assistance Data
$T_{UEProc-LPPLocationRe}$	5	LPP Request/Provide Location Information
$T_{UEProc-MAC-SRSAct}$	1-3	MAC-CE SRS Activation/Deactivation
$T_{gNBProc-RRC}$	3	RRC Processing
$T_{gNBProc-NRPPa}$	3	NRPPa Processing
$T_{gNBProc-NAS/LPP}$	3	NAS/LPP Processing
$T_{AMFProc}$	3	AMF Processing
$T_{LMFProc}$	3	LMF Processing
Signalling Propagation Delays between Nodes		
T_{UE-gNB}	0-0.5	
$T_{gNB-AMF}$	3-10	
$T_{AMF-LMF}$	1-10	
$T_{AMF-GMLC}$	3-10	
Positioning Measurement Latencies		
$T_{LMF-Calc}$	2-30	Position Calculation latency
$T_{DL-Meas}$	88.5	Estimated minimum DL PRS measurement time in Rel.16 can be 88.5ms depending on DL PRS configuration settings.
$T_{UL-Meas}$	12	SRS for positioning measurement time of 12 ms can be achieved under certain SRS for positioning configuration settings depending on the frame configuration.

Note 4: On delays related to node processing and Network Signalling interfaces, the following should also be considered:

- There can be network latency variations depending on the deployment distance between gNB and AMF, and depending on the backhaul type;
- gNB split architecture adds F1AP processing latency and CU-DU signaling propagation delay;
- One or more network latency components may not be present in certain specific deployments, e.g. where logical nodes such as gNB and AMF are co-located.

5.2.3.2 Network efficiency

PRS/SRS resource utilization is the metric used to evaluate network efficiency.

5.2.3.3 Device efficiency

The UE power consumption models developed in TR38.840 can be considered as the starting point for defining the UE power consumption model for the evaluation for NR positioning. For evaluations, it is up to each source to detail their methodology (including the power model) for evaluation.

6 Additional scenarios and channel models for NR positioning enhancements

The scenario parameters common to all the scenarios in the study are detailed in table 6-1. Additionally, blockage model is not considered. For evaluations including UE mobility, the spatial consistency procedure defined in TR 38.901 is taken into consideration.

The evaluation methodology does not define any baseline reference signals. Configurations of DL PRS and SRS supported by Rel-16 specifications are used for evaluation of the achievable performance based on Rel-16 positioning technologies.

Table 6-1: Common scenario parameters applicable for all scenarios

	FR1 Specific Values	FR2 Specific Values
Carrier frequency, GHz	3.5GHz	28GHz
Bandwidth, MHz	100MHz	400MHz
Subcarrier spacing, kHz	30kHz for 100MHz	120kHz
gNB model parameters		
gNB noise figure, dB	5dB	7dB
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 configuration	Panel model 1 – Note 1 Mg = 1, Ng = 1, P = 2, dH = 0.5λ, (M, N, P, Mg, Ng) = (1, 2, 2, 1, 1)	Baseline: Multi-panel Configuration 1 and Panel Configuration a – Note 1 <ul style="list-style-type: none">- Multi-panel Configuration 1: (Mg, Ng) = (1, 2); Θmg,ng=90°; Ω0,1=Ω0,0+180°; (dg,H, dg,V)=(0,0)- Panel Configuration a:<ul style="list-style-type: none">- Each antenna array has shape dH=dV=0.5λ- Config a: (M, N, P) = (2, 4, 2),- the polarization angles are 0° and 90°- The antenna elements of the same polarization of the same panel is virtualized into one TXRU Optional: 4-panels UE: <ul style="list-style-type: none">- The antenna elements of the same polarization of the same panel is virtualized into one TXRU
UE antenna radiation pattern	Omni, 0dBi	Antenna model according to Table 6.1.1-2 in TR 38.855
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 an eNB and a timing reference source which is assumed to have perfect timing, subject to a largest timing difference of T2 ns, where T2 = 2*T1 <ul style="list-style-type: none">– 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: <ul style="list-style-type: none">- 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: <ul style="list-style-type: none">- For each UE drop,<ul style="list-style-type: none">o For each panel (in case of multiple panels)<ul style="list-style-type: none">▪ 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<ul style="list-style-type: none">o For each panel (in case of multiple panels)<ul style="list-style-type: none">▪ 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.	
Note 1: According to TR 38.802 Note 2: According to TR 38.901		

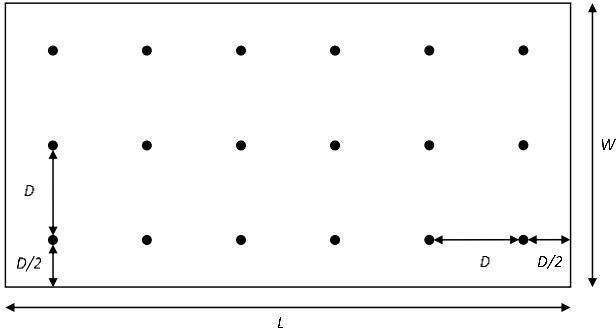
6.1 IIoT use cases

For evaluating baseline performance, the following scenarios (with various options/configurations) are defined for RAT-dependent positioning techniques for the NR positioning enhancements study

- Scenario 1. InF-SH for FR1 and FR2
- Scenario 2. InF-DH for FR1 and FR2

In the evaluation of all scenarios, the absolute-time-of arrival model defined in TR 38.901 is considered, without modification. Parameters specific to scenario 1 and 2 are detailed in table 6.1-1

Table 6.1-1: Parameters common to InF scenarios

		FR1 Specific Values	FR2 Specific Values
Channel model		InF-SH, InF-DH	InF-SH, InF-DH
Layout	Hall size	InF-SH: (baseline) 300x150 m (optional) 120x60 m InF-DH: (baseline) 120x60 m (optional) 300x150 m	
	BS locations	18 BSs on a square lattice with spacing D , located $D/2$ from the walls. - for the small hall ($L=120\text{m} \times W=60\text{m}$): $D=20\text{m}$ - for the big hall ($L=300\text{m} \times W=150\text{m}$): $D=50\text{m}$ 	
	Room height	10m	
Total gNB TX power, dBm		24dBm	24dBm EIRP should not exceed 58 dBm
gNB antenna configuration		(M, N, P, Mg, Ng) = (4, 4, 2, 1, 1), $dH=dV=0.5\lambda$ – Note 1	(M, N, P, Mg, Ng) = (4, 8, 2, 1, 1), $dH=dV=0.5\lambda$ – Note 1 One TXRU per polarization per panel is assumed
gNB antenna radiation pattern		Single sector – Note 1	3-sector antenna configuration – Note 1
Penetration loss		0dB	
Number of floors		1	
UE horizontal drop procedure		Uniformly distributed over the horizontal evaluation area for obtaining the CDF values for positioning accuracy. The evaluation area should be - (baseline) at least the convex hull of the horizontal BS deployment. - (optional) It can also be the whole hall area if the CDF values for positioning accuracy is obtained from whole hall area.	
UE antenna height		Baseline: 1.5m (Optional): uniformly distributed within $[0.5, X2]\text{m}$, where $X2 = 2\text{m}$ for scenario 1 (InF-SH) and $X2=h_c$ for scenario 2 (InF-DH)	
UE mobility		3km/h	
Min gNB-UE distance (2D), m		0m	
gNB antenna height		Baseline: 8m (Optional): two fixed heights, either $\{4, 8\}$ m, or $\{\max(4, h_c), 8\}$.	
Clutter parameters: {density r , height h_c , size $d_{clutter}$ }		Low clutter density: {20%, 2m, 10m} High clutter density: - Baseline): {40%, 2m, 2m} for fixed UE antenna height and gNB antenna height - (Optional): {40%, 3m, 5m} - (Optional): {60%, 6m, 2m}	

Note 1: According to Table A.2.1-7 in TR 38.802

6.2 General commercial use cases

For general commercial use cases, Rel-16 scenarios and channel models in TR 38.855 are reused. For the absolute time of arrival modelling in IOO, UMa, Umi, sources may provide the details of their model, if any.

7 Studied NR positioning enhancements

The following enhancements have been considered during this study:

- Partial staggering and non-staggering RE mapping of SRS for positioning with different combinations of comb-factors and symbol lengths, including the methods/signalling for addressing potential time-domain aliasing due to the partial/non-staggering RE mapping.
- Semi-persistent and a-periodic transmission and reception of DL PRS
 - Semi-persistent means MAC-CE triggered
 - Aperiodic would correspond to DCI-triggered
- On-demand transmission and reception of DL PRS
 - On-demand corresponds to the UE-initiated or network-initiated request of PRS and/or SRS, i.e. UE or LMF request/suggesting/recommending specific PRS pattern, ON/OFF, periodicity, BW, etc.
- Multipath mitigation techniques including but not limited to the following:
 - The applicable scenarios and performance benefits of multipath mitigation techniques
 - The methods/measurement/signaling for the LOS/NLOS detection and identification
 - The measurements for supporting the multipath mitigation/utilization
 - The procedure and signaling for supporting the multipath mitigation/utilization
 - Implementation-based solutions (e.g., outlier rejection) without the need of any additional specified method/measurements/procedures/signaling.
 - Note: The above study applies to DL only, UL only, DL+UL positioning solutions for UE-based and UE-assisted positioning.
- NR positioning for UEs in RRC_IDLE state and UEs in RRC_INACTIVE state, including the benefits on latency, network/UE efficiency and UE power consumption
- For reducing NR positioning latency, more efficient signaling & procedures enabling a device to request and report positioning information, which may include, but not limited to, the following aspects:
 - DL PRS/SRS configuration, activation or triggering.
 - The request for positioning information (the assistance data, etc.).
 - The report of positioning information (the measurement report, etc.).
 - Note: It is not within RAN1 scope to analyze positioning architecture enhancements to enable such more efficient signaling & procedures.
 - Note: RAN1 does not make any assumptions on whether the LCS architecture specified in TS 23.273 is enhanced or not.
- Simultaneous transmission by the UE and reception by the gNB of the SRS for positioning across multiple CCs and multiple slots, including
 - The scenarios and performance benefits of the enhancement
 - The impact of channel spacing, TA and timing offset, phase offset, frequency error, and power imbalance across slots or CCs to the positioning performance for intra-band contiguous/ non-contiguous and inter-band scenarios
- Scenario, benefits, and methods for improving the accuracy of the UL AoA and DL-AoD methods for both UE-based and network-based (including UE-assisted) positioning
- Scenario, benefits, methods and signaling for improving positioning accuracy in the presence of the UE Rx/Tx transmission delays, and/or gNB Rx/Tx transmission delays for UE-based and network-based (including UE-assisted) positioning.
- Aggregating multiple DL positioning frequency layers of the same or different bands for improving positioning performance for both intra-band and inter-band scenarios
 - The scenarios and performance benefits of aggregating multiple DL positioning frequency layers

- The impact of channel spacing, timing offset, phase offset, frequency error, and power imbalance among CCs to the positioning performance for intra-band contiguous/ non-contiguous and inter-band scenarios
- UE complexity considerations
- UE positioning procedures under the scope of RRC_IDLE/RRC_INACTIVE positioning, i.e. performed when the UE is in RRC_IDLE/RRC_INACTIVE.
 - NAS-transported positioning signalling
 - LCS messages defined in Clause 4.1.2 for location services in TS 24.571 [29]
 - LPP signaling for positioning (e.g., Capability transfer, Assistance data transfer, Location information transfer)
 - NRPPa
 - E-CID information transfer (UE-associated)
 - Positioning information transfer (UE-associated)
 - Measurement information transfer (non-UE-associated)
 - Uu Signaling and procedure
 - RRC signaling for positioning (e.g., posSRS configuration)
 - MAC procedure/L1 signaling (e.g., activation/deactivation for semi-persistent/aperiodic posSRS)
 - Transmission of UL-PRS and reception of DL-PRS
 - Reception for assistance information broadcast

8 Performance evaluations for Rel-17 targets

8.1 Performance analysis of Rel-16 positioning solutions

This clause presents the observations made by sources regarding Rel-16 positioning solutions. Detailed results can be found in annex C.1.

8.1.1 Positioning accuracy analysis

8.1.1.1 Observations from source [4]

Table 8.1.1.1-1 captures observations based on NR positioning evaluations results for horizontal location error for baseline scenarios.

Table 8.1.1.1-2 captures observations based on NR positioning evaluations results for horizontal location error for modified DH and 3D positioning.

Table 8.1.1.1-3 captures observations based on NR positioning evaluations results for horizontal location error for UE/gNB calibration error.

Table 8.1.1.1-4 captures observations based on NR positioning evaluations results for vertical location error for modified DH and 3D positioning.

Table 8.1.1.1-1: Rel.16 NR positioning (baseline) – horizontal accuracy performance summary [4]

Simulation case (Horizontal Error)	Accuracy achieved @[90]%	Commercial horizontal accuracy requirements [1]m @[90]% are met - Yes/No. If no, provide performance gaps @[90]%	IIoT horizontal accuracy requirements of [0.2]m @[90]% are met - Yes/No. If no, provide performance gaps @[90]%	IIoT horizontal accuracy requirements of [0.5]m @[90]% are met - Yes/No. If no, provide performance gaps @[90]%
1, InF-SH, FR1, DL-TDOA	1.964	0.964	1.764	1.464
2, InF-SH, FR1, UL-TDOA	1.0277	0.0277	0.8277	0.5277
3, InF-SH, FR1, UL-TDOA/AoA	0.2682	Yes	0.0682	Yes
4, InF-SH, FR1, Multi-RTT	1.6992	0.6992	1.4992	1.1992
5, InF-DH422, FR1, DL-TDOA	15.635	14.635	15.435	15.135
6, InF-DH422, FR1, UL-TDOA	9.6631	9.163	9.963	9.663
7, InF-DH422, FR1, UL-TDOA/AoA	0.8016	Yes	0.6016	0.3016
8, InF-DH422, FR1, Multi-RTT	7.311	6.311	7.111	6.811
9, InF-SH, FR2, DL-TDOA	0.9633	Yes	0.7633	0.4633
10, InF-SH, FR2, DL-TDOA/AoD	0.0654	Yes	Yes	Yes
11, InF-SH, FR2, UL-TDOA/AoA	0.0694	Yes	Yes	Yes
12, InF-SH, FR2, Multi-RTT	0.4496	Yes	0.2496	Yes
13, InF-DH422, FR2, DL-TDOA	9.6798	8.6798	9.4798	9.1798
14, InF-DH422, FR2, DL-TDOA/AoD	0.7197	Yes	0.5197	0.2197
15, InF-DH422, FR2, UL-TDOA/AoA	0.7086	Yes	0.5086	0.2086
16, InF-DH422, FR2, Multi-RTT	4.2895	3.2895	4.0895	3.7895

Table 8.1.1.1-2: Rel.16 NR positioning (modified DH and 3D positioning) – horizontal accuracy performance summary [4]

Simulation case (Horizontal Error)	Accuracy achieved @[90]%	Commercial horizontal accuracy requirements [1]m @[90]% are met - Yes/No. If no, provide performance gaps @[90]%	IIoT horizontal accuracy requirements of [0.2]m @[90]% are met - Yes/No. If no, provide performance gaps @[90]%	IIoT horizontal accuracy requirements of [0.5]m @[90]% are met - Yes/No. If no, provide performance gaps @[90]%
101, InF-DH435, FR1, UL-TDOA/AoA	1.3012	0.3012	1.1012	0.8012
102, InF-DH435, FR1, Multi-RTT	9.8411	8.8411	9.6411	9.3411
103, InF-DH435-3D, FR1, UL-TDOA/AoA	4.3405(H)	3.3405	4.1405	3.8405
104, InF-DH435-3D, FR1, Multi-RTT	16.0515(H)	15.0515	15.8515	15.5515
105, InF-DH435, FR2, UL-TDOA/AoA	1.1486	0.1486	0.9486	0.6486
106, InF-DH435, FR2, Multi-RTT	5.46	4.46	5.26	4.96
107, InF-DH435-3D, FR2, UL-TDOA/AoA	2.4365(H)	1.4365	2.2365	1.9365
108, InF-DH435-3D, FR2, Multi-RTT	15.5828(H)	14.5828	15.3828	15.0828

Table 8.1.1.1-3: Rel.16 NR positioning (UE/gNB calibration error) – horizontal accuracy performance summary [4]

Simulation case (Horizontal Error)	Accuracy achieved @[90]%	Commercial horizontal accuracy requirements [1]m @[90]% are met - Yes/No. If no, provide performance gaps @[90]%	IIoT horizontal accuracy requirements of [0.2]m @[90]% are met - Yes/No. If no, provide performance gaps @[90]%	IIoT horizontal accuracy requirements of [0.5]m @[90]% are met - Yes/No. If no, provide performance gaps @[90]%
201, InF-SH, FR1, DL-TDOA, Group Delay Error	1.458	0.458	1.258	0.958
202, InF-SH, FR1, UL-TDOA, Group delay error	1.2343	0.2343	1.0343	0.7343
203, InF-SH, FR1, UL- TDOA/AoA, Group delay error	0.3251	Yes	0.1251	Yes
204, InF-SH, FR1, Multi-RTT, Group delay error	4.2662	3.2662	4.0662	3.7662
205, InF-DH422, FR1, DL- TDOA, Group delay error	15.039	14.039	14.839	14.539
206, InF-DH422, FR1, UL- TDOA, Group delay error	9.4102	8.4102	9.2102	8.9102
207, InF-DH422, FR1, UL- TDOA/AoA, Group delay error	0.8662	Yes	0.6662	0.3662
208, InF-DH422, FR1, Multi- RTT, Group delay error	9.5701	8.5701	9.3701	9.0701
209, InF-SH, FR1, UL-AoA	0.1119	Yes	Yes	Yes
210, InF-SH, FR1, UL-AoA, Angle error 1 degree	1.1676	0.1676	0.9676	0.6676
211, InF-SH, FR1, UL-AoA, Angle error 2 degrees	2.1732	1.1732	1.9732	1.6732
212, InF-SH, FR1, UL-AoA, Angle error 5 degrees	5.3982	4.3982	5.1982	4.8982

Table 8.1.1.1-4: Rel.16 NR positioning (modified DH and 3D positioning) – vertical accuracy performance summary [4]

Simulation case (Vertical Error)	Accuracy achieved @[90]%	Commercial vertical accuracy requirements [3]m @[90]% are met - Yes/No. If no, provide performance gaps @[90]%	IIoT vertical accuracy requirements of [0.2]m @[90]% are met - Yes/No. If no, provide performance gaps @[90]%	IIoT vertical accuracy requirements of [1]m at @[90]% are met - Yes/No. If no, provide performance gaps @[90]%
103, InF-DH435-3D, FR1, UL-TDOA/AoA	1.1585(V)	Yes	0.9585	0.1585
104, InF-DH435-3D, FR1, Multi-RTT	1.6675(V)	Yes	1.4675	0.6675
107, InF-DH435-3D, FR2, UL-TDOA/AoA	0.4593(V)	Yes	0.2593	Yes
108, InF-DH435-3D, FR2, Multi-RTT	1.8800(V)	Yes	1.68	0.88

8.1.1.2 Observations from source [7]

Table 8.1.1.2-1: Rel.16 NR positioning – horizontal accuracy performance summary [7]

Simulation case (Horizontal Error)	Accuracy achieved @[90]%
Case 1	0.603
Case 2	0.568
Case 3	0.704
Case 4	0.943
Case 5	1.479
Case 6	0.092
Case 7	0.090
Case 8	0.300
Case 9	0.615
Case 10	1.224
Case 11	12.433
Case 12	12.345
Case13	12.386
Case 14	12.368
Case 15	12.458
Case 16	14.759
Case 17	12.174
Case 18	10.815
Case 19	12.285
Case 20	14.845

Table 8.1.1.2-2: Rel.16 NR positioning – vertical accuracy performance summary [7]

Simulation case (Vertical Error)	Accuracy achieved @[90]%
Case 21	0.979
Case 22	0.459
Case 23	1.419
Case 24	1.271

8.1.1.3 Observations from source [8]

Table 8.1.1.3-1 captures observations based on NR positioning evaluations results for horizontal location error.

Table 8.1.1.3-1: Rel.16 NR positioning – horizontal accuracy performance summary [8]

Simulation case (Horizontal Error)	Accuracy achieved @[90]%	IIoT horizontal accuracy requirements of [0.2]m @[90]%are met - Yes/No. If No, provide performance gaps @[90]%	IIoT horizontal accuracy requirements of [0.5]m @[90]%are met - Yes/No. If No, provide performance gaps @[90]%
[Case 1], [InF-SH-2D], [FR1], [DL-TDOA]	0.1650	Yes	Yes
[Case 2], [InF-SH-2D], [FR1], [UL-TDOA]	0.1551	Yes	Yes
[Case 3], [InF-SH-2D], [FR1], [Multi-RTT]	0.1650	Yes	Yes
[Case 4], [InF-SH-3D], [FR1], [DL-TDOA]	0.2045	No (0.0045)	Yes
[Case 5], [InF-SH-3D], [FR1], [UL-TDOA]	0.2574	No (0.0574)	Yes
[Case 6], [InF-SH-3D], [FR1], [UL-TDOA+UL-AOA]	0.2677	No (0.0677)	Yes
[Case 7], [InF-SH-3D], [FR1], [Multi-RTT]	0.2540	No (0.054)	Yes
[Case 8], [InF-DH-2D], [FR1], [DL-TDOA]	0.1693	Yes	Yes
[Case 9], [InF-DH-2D], [FR1], [UL-TDOA]	0.1184	Yes	Yes
[Case 10], [InF-DH-2D], [FR1], [Multi-RTT]	0.1237	Yes	Yes
[Case 11], [InF-DH-3D], [FR1], [DL-TDOA]	0.7089	No (0.5089)	No (0.2089)
[Case 12], [InF-DH-3D], [FR1], [UL-TDOA]	0.6937	No (0.4937)	No (0.1937)
[Case 13], [InF-DH-3D], [FR1], [UL-TDOA+UL-AOA]	0.151	Yes	Yes
[Case 14], [InF-DH-3D], [FR1], [Multi-RTT]	0.692	No (0.362)	No (0.062)
[Case 15], [IOO], [FR1], [DL- TDOA]	0.2288	—	—
[Case 16], [IOO], [FR1], [UL- TDOA]	0.1836	—	—
[Case 17], [IOO], [FR1], [UL- TDOA+UL-AOA]	0.1219	—	—
[Case 18], [IOO], [FR1], [Multi-RTT]	0.283	—	—
[Case 19], [IOO], [FR1], [DL- TDOA]	32.4509	—	—
[Case 20], [IOO], [FR1], [UL- TDOA]	32.0927	—	—
[Case 21], [IOO], [FR1], [UL- TDOA+UL-AOA]	9.2356	—	—
[Case 22], [IOO], [FR1], [Multi-RTT]	1.3668	—	—
[Case 23], [InF-SH-2D], [FR2], [DL-TDOA]	0.0372	Yes	Yes
[Case 24], [InF-SH-2D], [FR2], [UL-TDOA]	0.0538	Yes	Yes
[Case 25], [InF-SH-3D], [FR2], [DL-TDOA]	0.0789	Yes	Yes
[Case 26], [InF-SH-3D], [FR2], [UL-TDOA]	0.0817	Yes	Yes
[Case 27], [InF-DH-2D], [FR2], [DL-TDOA]	0.0388	Yes	Yes
[Case 28], [InF-DH-2D], [FR2], [UL-TDOA]	0.0553	Yes	Yes
[Case 29], [InF-DH-3D], [FR2], [DL-TDOA]	0.7033	No (0.5033)	No (0.2033)

[Case 30], [InF-DH-3D], [FR2], [UL-TDOA]	0.6848	No (0.4848)	No (0.1848)
[Case 31], [IOO], [FR2], [DL-TDOA]	0.0406	—	—
[Case 32], [IOO], [FR2], [UL-TDOA]	0.0397	—	—
[Case 33], [IOO], [FR2], [Multi-RTT]	0.0402	—	—
[Case 34], [IOO], [FR2], [DL-TDOA]	32.3809	—	—
[Case 35], [IOO], [FR2], [UL-TDOA]	32.0887	—	—
[Case 36], [IOO], [FR2], [Multi-RTT]	1.2681	—	—

Table 8.1.1.3-2 captures observations based on NR positioning evaluations results for vertical location error.

Table 8.1.1.3-2: Rel.16 NR positioning – vertical accuracy performance summary [8]

Simulation case (Vertical Error)	Accuracy achieved @[90]%	IoT vertical accuracy requirements of [0.2]m @[90]% are met - Yes/No. If No, provide performance gaps@[90]%	IoT vertical accuracy requirements of [1]m at @[90]% are met - Yes/No. If No, provide performance gaps@[90]%
[Case 4], [InF-SH-3D], [FR1], [DL-TDOA]	1.8954	No (1.6954)	No (0.8954)
[Case 5], [InF-SH-3D], [FR1], [UL-TDOA]	2.0599	No (1.6599)	No (1.0599)
[Case 6], [InF-SH-3D], [FR1], [UL-TDOA+UL-AOA]	2.256	No (2.056)	No (1.256)
[Case 7], [InF-SH-3D], [FR1], [Multi-RTT]	2.18	No (1.98)	No (1.18)
[Case 11], [InF-DH-3D], [FR1], [DL-TDOA]	2.9917	No (2.7917)	No (1.9917)
[Case 12], [InF-DH-3D], [FR1], [UL-TDOA]	2.049	No (1.849)	No (1.049)
[Case 13], [InF-DH-3D], [FR1], [UL-TDOA+UL-AOA]	0.633	No (0.433)	Yes
[Case 14], [InF-DH-3D], [FR1], [Multi-RTT]	2.82	No (2.62)	No (1.82)
[Case 25], [InF-SH-3D], [FR2], [DL-TDOA]	0.6283	No (0.4283)	Yes
[Case 26], [InF-SH-3D], [FR2], [UL-TDOA]	0.8304	No (0.6304)	Yes
[Case 29], [InF-DH-3D], [FR2], [DL-TDOA]	3.0578	No (2.8578)	No (2.0578)
[Case 30], [InF-DH-3D], [FR2], [UL-TDOA]	3.1267	No (2.9267)	No (2.1267)

8.1.1.4 Observations from source [13]

Table 8.1.1.4-1: Rel.16 NR positioning – horizontal accuracy performance summary [13]

Simulation case (Horizontal Error)	Accuracy achieved @[90]%
Case 1, [InF-SH, DL-TDOA, FR1]	4.35
Case 2, [InF-DH, DL-TDOA, FR1]	7.16
Case 3, [IOO, DL-TDOA, FR1]	4.31
Case 4, [IOO, DL-TDOA, FR1]	6.50
Case 5, [UMi, DL-TDOA, FR1]	23.81
Case 6, [InF-SH, DL-TDOA, FR1]	1.65
Case 7, [InF-DH, DL-TDOA, FR1]	4.99

8.1.1.5 Observations from source [5]

Table 8.1.1.5-1.1 to Table 8.1.1.5-1.3 captures observations based on NR positioning evaluations results for horizontal location error.

Table 8.1.1.5-1.1: Rel.16 NR positioning – horizontal accuracy performance summary for baseline with perfect synchronization [5]

Simulation case (Horizontal Error)	Accuracy achieved @[90]%	IIoT horizontal accuracy requirements of [0.2]m @[90]% are met - Yes/No. If no, provide performance gaps @[90]%
[Case 1], [SH, perfect sync], [FR1], [DL-TDOA, MUSIC, select based on RSRP]	4.15	3.95
[Case 3], [SH, perfect sync], [FR2], [DL-TDOA, MUSIC, select based on RSRP]	2.97	2.77
[Case 5], [DH, perfect sync], [FR1], [DL-TDOA, MUSIC, select based on RSRP]	5.92	5.72
[Case 7], [DH, perfect sync], [FR2], [DL-TDOA, MUSIC, select based on RSRP]	5.77	5.57
[Case 11], [SH, perfect sync], [FR1], [DL-TDOA, MUSIC, select based on first/median peak]	0.094	Yes
[Case 13], [SH, perfect sync], [FR2], [DL-TDOA, MUSIC, select based on first/median peak]	0.031	Yes
[Case 15], [DH, perfect sync], [FR1], [DL-TDOA, MUSIC, select based on first/median peak]	0.60	0.4
[Case 17], [DH, perfect sync], [FR2], [DL-TDOA, MUSIC, select based on first/median peak]	0.049	Yes
[Case 19], [SH, perfect sync], [FR1], [UL-TDOA, MUSIC, select based on RSRP]	4.22	4.02
[Case 21], [SH, perfect sync], [FR2], [UL-TDOA, MUSIC, select based on RSRP]	4.07	3.87
[Case 23], [DH, perfect sync], [FR1], [UL-TDOA, MUSIC, select based on RSRP]	5.85	5.65
[Case 25], [DH, perfect sync], [FR2], [UL-TDOA, MUSIC, select based on RSRP]	5.76	5.56
[Case 27], [SH, perfect sync], [FR1], [UL-TDOA, MUSIC, select based on first/median peak]	0.087	Yes
[Case 29], [SH, perfect sync], [FR2], [UL-TDOA, MUSIC, select based on first/median peak]	0.032	Yes
[Case 31], [DH, perfect sync], [FR1], [UL-TDOA, MUSIC, select based on first/median peak]	0.60	0.40
[Case 33], [DH, perfect sync], [FR2], [UL-TDOA, MUSIC, select based on first/median peak]	0.051	Yes
[Case 35], [SH, perfect sync], [FR1], [UL-AOA]	5.93	5.73
[Case 37], [DH, perfect sync], [FR1], [UL-AOA]	5.48	5.28

[Case 39], [SH, perfect sync], [FR1], [UL-TDOA+UL-AOA]	0.41	0.21
[Case 41], [DH, perfect sync], [FR1], [UL-TDOA+UL-AOA]	0.68	0.48
[Case 43], [SH, perfect sync], [FR1], [Multi-RTT, MUSIC, select based on RSRP]	4.25	4.05
[Case 45], [SH, perfect sync], [FR2], [Multi-RTT, MUSIC, select based on RSRP]	3.96	3.76
[Case 47], [DH, perfect sync], [FR1], [Multi-RTT, MUSIC, select based on RSRP]	5.88	5.68
[Case 49], [DH, perfect sync], [FR2], [Multi-RTT, MUSIC, select based on RSRP]	5.74	5.54
[Case 51], [SH, perfect sync], [FR1], [Multi-RTT, MUSIC, select based on first/median peak]	0.10	Yes
[Case 53], [SH, perfect sync], [FR2], [Multi-RTT, MUSIC, select based on first/median peak]	0.031	Yes
[Case 55], [DH, perfect sync], [FR1], [Multi-RTT, MUSIC, select based on first/median peak]	0.60	0.40
[Case 57], [DH, perfect sync], [FR2], [Multi-RTT, MUSIC, select based on first/median peak]	0.051	Yes

Table 8.1.1.5-1.2: Rel.16 NR positioning – horizontal accuracy performance summary for baseline with 50ns synchronization error [5]

Simulation case (Horizontal Error)	Accuracy achieved @[90]%	IIoT horizontal accuracy requirements of [0.2]m @[90]% are met - Yes/No. If no, provide performance gaps @[90]%
[Case 2], [SH, sync error 50ns], [FR1], [DL-TDOA, MUSIC, select based on RSRP]	24.06	23.86
[Case 4], [SH, sync error 50ns], [FR2], [DL-TDOA, MUSIC, select based on RSRP]	23.21	23.01
[Case 6], [DH, sync error 50ns], [FR1], [DL-TDOA, MUSIC, select based on RSRP]	23.79	23.59
[Case 8], [DH, sync error 50ns], [FR2], [DL-TDOA, MUSIC, select based on RSRP]	22.90	22.70
[Case 12], [SH, sync error 50ns], [FR1], [DL-TDOA, MUSIC, select based on first/median peak]	26.09	25.89
[Case 14], [SH, sync error 50ns], [FR2], [DL-TDOA, MUSIC, select based on first/median peak]	25.67	25.47
[Case 16], [DH, sync error 50ns], [FR1], [DL-TDOA, MUSIC, select based on first/median peak]	20.30	20.10
[Case 18], [DH, sync error 50ns], [FR2], [DL-TDOA, MUSIC, select based on first/median peak]	20.16	19.96
[Case 20], [SH, sync error 50ns], [FR1], [UL-TDOA, MUSIC, select based on RSRP]	24.51	24.31
[Case 22], [SH, sync error 50ns], [FR2], [UL-TDOA, MUSIC, select based on RSRP]	23.21	23.01
[Case 24], [DH, sync error 50ns], [FR1], [UL-TDOA, MUSIC, select based on RSRP]	22.90	22.70
[Case 26], [DH, sync error 50ns], [FR2], [UL-TDOA, MUSIC, select based on RSRP]	18.92	18.72
[Case 28], [SH, sync error 50ns], [FR1], [UL-TDOA, MUSIC, select based on first/median peak]	27.70	27.50
[Case 30], [SH, sync error 50ns], [FR2], [UL-TDOA, MUSIC, select based on first/median peak]	25.67	25.47
[Case 32], [DH, sync error 50ns], [FR1], [UL-TDOA, MUSIC, select based on first/median peak]	22.01	21.81

[Case 34], [DH, sync error 50ns], [FR2], [UL-TDOA, MUSIC, select based on first/median peak]	19.74	19.54
[Case 36], [SH, sync error 50ns], [FR1], [UL-AOA]	6.20	6.00
[Case 38], [DH, sync error 50ns], [FR1], [UL-AOA]	5.76	5.56
[Case 40], [SH, sync error 50ns], [FR1], [UL-TDOA+UL-AOA]	0.43	0.23
[Case 42], [DH, sync error 50ns], [FR1], [UL-TDOA+UL-AOA]	0.77	0.57
[Case 44], [SH, sync error 50ns], [FR1], [Multi-RTT, MUSIC, select based on RSRP]	4.71	4.51
[Case 46], [SH, sync error 50ns], [FR2], [Multi-RTT, MUSIC, select based on RSRP]	4.13	3.93
[Case 48], [DH, sync error 50ns], [FR1], [Multi-RTT, MUSIC, select based on RSRP]	6.20	6.00
[Case 50], [DH, sync error 50ns], [FR2], [Multi-RTT, MUSIC, select based on RSRP]	6.23	6.03
[Case 52], [SH, sync error 50ns], [FR1], [Multi-RTT, MUSIC, select based on first/median peak]	0.10	Yes
[Case 54], [SH, sync error 50ns], [FR2], [Multi-RTT, MUSIC, select based on first/median peak]	0.030	Yes
[Case 56], [DH, sync error 50ns], [FR1], [Multi-RTT, MUSIC, select based on first/median peak]	0.78	0.58
[Case 58], [DH, sync error 50ns], [FR2], [Multi-RTT, MUSIC, select based on first/median peak]	0.055	Yes

Table 8.1.1.5-1.3: Rel.16 NR positioning – horizontal accuracy performance summary for DH {60%,6,2} with perfect synchronization [5]

Simulation case (Horizontal Error)	Accuracy achieved @[90]%	IoT horizontal accuracy requirements of [0.2]m @[90]%are met - Yes/No. If no, provide performance gaps @[90]%
[Case 9], [DH {0.6,6,2}, perfect sync], [FR1], [DL-TDOA, MUSIC, select based on RSRP]	18.71	18.51
[Case 10], [DH {0.6,6,2}, perfect sync], [FR2], [DL-TDOA, MUSIC, select based on RSRP]	15.09	14.89

Table 8.1.1.5-2 captures observations based on NR positioning evaluations results for vertical location error.

Table 8.1.1.5-2: Rel.16 NR positioning – vertical accuracy performance summary [23]

Simulation case (Vertical Error)	Accuracy achieved @[90]%	IIoT horizontal accuracy requirements of [1]m @[90]% are met - Yes/No. If no, provide performance gaps @[90]%
[Case V1], [SH, perfect sync], [FR1], [BS height = 8m UE height =1.5m] [UL- AOA+ZOA, MUSIC, select based on first/median peak]	0.66	Yes
[Case V2], [DH, perfect sync], [FR1], [BS height = 8m UE height =1.5m] [UL- AOA+ZOA, MUSIC, select based on first/median peak]	1.12	0.12
[Case V3], [SH, perfect sync], [FR1], [BS height = {4,8}m UE height =1.5m] [UL- AOA+ZOA, MUSIC, select based on first/median peak]	0.82	Yes
[Case V4], [DH, perfect sync], [FR1], [BS height = {4,8}m UE height =1.5m] [UL- AOA+ZOA, MUSIC, select based on first/median peak]	1.39	0.39
[Case V5], [SH, perfect sync], [FR1], [BS height = 8m UE height =[0.5,2]m] [UL- AOA+ZOA, MUSIC, select based on first/median peak]	1.05	0.05
[Case V6], [DH, perfect sync], [FR1], [BS height = 8m UE height =[0.5,2]m] [UL- AOA+ZOA, MUSIC, select based on first/median peak]	5.46	4.46
[Case V7], [SH, perfect sync], [FR1], [BS height = {4,8}m UE height =[0.5,2]m] [UL- AOA+ZOA, MUSIC, select based on first/median peak]	1.21	0.21
[Case V8], [DH, perfect sync], [FR1], [BS height = {4,8}m UE height =[0.5,2]m] [UL- AOA+ZOA, MUSIC, select based on first/median peak]	9.06	8.06

8.1.1.6 Observations from source [12]

Table 8.1.1.6-1 captures observations based on NR positioning evaluations results for horizontal location error.

Table 8.1.1.6-1: Rel.16 NR positioning – horizontal accuracy performance summary [12]

Simulation case (Horizontal Error)	Accuracy achieved @[90]%	IoT horizontal accuracy requirements of [0.2]m @[90]% are met - Yes/No. If no, provide performance gaps @[90]%	IoT horizontal accuracy requirements of [0.5]m @[90]% are met - Yes/No. If no, provide performance gaps @[90]%
Case1, (InF-SH, FR1)	8.5	No, 8.3	No, 8.00
Case2, (InF-DH, FR1)	14.95	No, 14.75	No, 14.55

8.1.1.7 Observations from source [10]

Table 8.1.1.7-1 captures observations based on NR positioning evaluations results for horizontal location error.

Table 8.1.1.7-1: Rel.16 NR positioning – horizontal accuracy performance summary [10]

Simulation case (Horizontal Error)	Accuracy achieved @[90]%
Case 1, InF-SH, FR1, DL-TDOA	0.85
Case 2, InF-DH, FR1, DL-TDOA	6.2
Case 3, InF-SH, FR2, DL-TDOA	0.65
Case 4, InF-DH, FR2, DL-TDOA	17.3
Case 5, InF-SH, FR1, UL-TDOA	0.77
Case 6, InF-DH, FR1, UL-TDOA	6.13
Case 7, InF-SH, FR2, UL-TDOA	0.9
Case 8, InF-DH, FR2, UL-TDOA	16.9
Case 9, InF-SH, FR1, Multi-RTT	0.25
Case 10, InF-DH, FR1, Multi-RTT	16.3
Case 11, InF-SH, FR2, Multi-RTT	0.9
Case 12, InF-DH, FR2, Multi-RTT	7.72

Table 8.1.1.7-2 captures observations based on NR positioning evaluations results for vertical location error.

Table 8.1.1.7-2: Rel.16 NR positioning – vertical accuracy performance summary [10]

Simulation case (Vertical Error)	Accuracy achieved @[90]%
Case 1, InF-SH, FR1, DL-TDOA	8.5
Case 2, InF-DH, FR1, DL-TDOA	12.6
Case 3, InF-SH, FR2, DL-TDOA	12.88
Case 4, InF-DH, FR2, DL-TDOA	63.4
Case 5, InF-SH, FR1, UL-TDOA	12.9
Case 6, InF-DH, FR1, UL-TDOA	12.9
Case 7, InF-SH, FR2, UL-TDOA	13
Case 8, InF-DH, FR2, UL-TDOA	62.78
Case 9, InF-SH, FR1, Multi-RTT	13.1
Case 10, InF-DH, FR1, Multi-RTT	66
Case 11, InF-SH, FR2, Multi-RTT	6.45
Case 12, InF-DH, FR2, Multi-RTT	7.07

8.1.1.8 Observations from source [14]

Table 8.1.1.8-1 captures observations based on NR positioning evaluations results for horizontal location error.

Table 8.1.1.8-1: Rel.16 NR positioning – horizontal accuracy performance summary [14]

Simulation case (Horizontal Error)	Accuracy achieved @[90]%
[Case 1], [InF-SH], [FR2], [400 MHz], [Comb-6], [6dB PB]	0.24
[Case 2], [InF-SH], [FR1], [100 MHz], [Comb-6], [6dB PB]	0.70
[Case 3], [InF-DH], [FR2], [400 MHz], [Comb-6], [6dB PB]	2.80
[Case 4], [InF-DH], [FR1], [100 MHz], [Comb-6], [6dB PB]	3.87
[Case 5], [InH-OO], [FR2], [400 MHz], [Comb-6], [6dB PB]	0.35
[Case 6], [InH-OO], [FR1], [100 MHz], [Comb-6], [6dB PB]	1.00

8.1.1.9 Observations from source [20]

Table 8.1.1.9-1 captures observations based on NR positioning evaluations results for horizontal location error.

Table 8.1.1.9-1: Rel.16 NR positioning – horizontal accuracy performance summary [20]

Simulation case (Horizontal Error)	Accuracy achieved @[90]%
[20], source1, UMa, FR1, DL-TDOA (50% UEs indoor)	11.97m (1 occasion) 7.04m (9 occasions)
[20], source1, UMa, FR1, DL-TDOA (100% UEs outdoor)	4.5m (1 occasion) 2.5m (9 occasions)
[20], source2, UMi, FR1, DL-TDOA	1.7m (1 occasion) 1.06m (9 occasions)
[20], source3, UMi, FR1, UL-TDOA	3.10m (1 occasion) 2.43m (9 occasions)
[20], source4, UMi, FR2, DL-TDOA	0.13m (1 occasion) 0.06m (9 occasions)
[20], source5, IOO, FR1, DL-TDOA	1.51m (1 occasion) 0.93m (9 occasions)
[20], source6, IOO, FR1, UL-TDOA	1.52m (1 occasion) 0.98m (9 occasions)
[20], source7, IOO, FR2, DL-TDOA	0.18m (1 occasion) 0.07m (9 occasions)
[20], source8, InF-SH, FR1, DL-TDOA	0.19m (convex hull UEs) 0.36m (all UEs)
[20], source9, InF-SH, FR1, UL-TDOA	0.18m (convex hull) 0.35m (all UEs)
[20], source10, InF-DH, FR1, DL-TDOA	7m (convex hull UEs) 14.3m (all UEs)
[20], source11, InF-DH, FR1, UL-TDOA	7.5m (convex hull UEs) 14.55m (all UEs)
[20], source12, InF-SH, FR2, DL-TDOA	0.0172m (no RX/Tx error-convex hull UEs) 3.34m (8ns Rx/Tx error-convex hull UEs) 0.0349m (no RX/Tx error-all UEs) 3.68m (8ns Rx/Tx error-all UEs)
[20], source13, InF-SH, FR2, UL-TDOA	0.0163m (no RX/Tx error-convex hull UEs) 3.36m (8ns Rx/Tx error-convex hull UEs) 0.0313m (no RX/Tx error-all UEs) 3.85m (8ns Rx/Tx error-all UEs)
[20], source14, InF-DH, FR2, DL-TDOA	7.06m (convex hull UEs) 14.95m (all UEs)
Ericsson15, InF-DH, FR2, UL-TDOA	6.98m (convex hull UEs) 13.48m (all UEs)

8.1.1.10 Observations from source [17]

Table 8.1.1.10-1 captures observations based on NR positioning evaluations results for horizontal location error.

Table 8.1.1.10-1: Rel.16 NR positioning – horizontal accuracy performance summary [17]

		90%
Case 1, InF FR1 DH ISD20, 100MHz, Link Quality, DL TDOA	Convex UEs	46.647m
	(Optional) All UEs	46.649m
Case 1, InF FR1 DH ISD20, 100MHz, RANSAC, DL TDOA	Convex UEs	0.044m
	(Optional) All UEs	0.045m
Case 2, InF FR1 SH ISD50, 100MHz, Link Quality, DL TDOA	Convex UEs	16.556m
	(Optional) All UEs	14.647m
Case 2, InF FR1 SH ISD50, 100MHz, RANSAC, DL TDOA	Convex UEs	0.038m
	(Optional) All UEs	0.034m
Case 3, InF FR1 DH ISD20, 100MHz, RANSAC, DL TDOA, Variable UE heights	Convex UEs	12.66m
	(Optional) All UEs	30.9m
Case 3, InF FR1 DH ISD20, 100MHz, RANSAC, DL TDOA, Fixed UE heights	Convex UEs	13.1m
	(Optional) All UEs	17.62m
Case 4, InF FR1 SH ISD50, 100MHz, RANSAC, DL TDOA, Unequal gNBs heights, Variable UE heights	Convex UEs	0.22m
	(Optional) All UEs	0.47m
Case 4, InF FR1 SH ISD50, 100MHz, RANSAC, DL TDOA, Unequal gNBs heights, Fixed UE heights	Convex UEs	0.12m
	(Optional) All UEs	0.36m

Horizontal Positioning Error (all UEs)	Beam Pair	90%
Case 5 InF-SH FR2 DL-TDOA	Earliest	0.019
	Strongest	0.027
Case 6 InF-SH FR2 3d mRTT	Earliest	0.015
Case 7 InF-DH FR2 DL-TDOA	Earliest	0.025
	Strongest	9.40
Case 8 InF-DH FR2 3d mRTT	Earliest	0.020
Case 5 InF-SH FR2 DL-TDOA	Earliest	0.0087
	Strongest	0.0170
Case 7 InF-DH FR2 DL-TDOA	Earliest	0.0096
	Strongest	1.6767
Case 12 UMi FR2 DL-TDOA	Earliest	0.040
	Strongest	6.32
Case 13 InH FR2 DL-TDOA	Earliest	0.024
	Strongest	0.053
Case 12 UMi FR2 DL-TDOA	Earliest	0.0403
	Strongest	6.3233
Case 13 InH FR2 DL-TDOA	Earliest	0.0113
	Strongest	0.0279

Horizontal Positioning Error		90%
Case 9, UMI, FR1, DL-TDOA, Without $\Delta\tau$, Perfect Sync, No Timing Errors, Likelihood Fusion Algorithm	(Optional) All UEs	0.6
Case 9, UMI, FR1, DL-TDOA, Without $\Delta\tau$, Perfect Sync, No Timing Errors, RANSAC Algorithm	(Optional) All UEs	3.2
Case 9, UMI, FR1, RTT, Without $\Delta\tau$, Perfect Sync, No Timing Errors, Likelihood Fusion Algorithm	(Optional) All UEs	0.4
Case 10, UMI, FR1, DL-TDOA, with $\Delta\tau$, Perfect Sync, No Timing Errors, Likelihood Fusion Algorithm	(Optional) All UEs	8
Case 10, UMI, FR1, RTT, with $\Delta\tau$, Perfect Sync, No Timing Errors, Likelihood Fusion Algorithm	(Optional) All UEs	9.4
Case 10, UMI, FR1, DL-TDOA, with $\Delta\tau$, Perfect Sync, No Timing Errors, RANSAC Algorithm	(Optional) All UEs	17.3
Case 10, UMI, FR1, DL-TDOA, with $\Delta\tau$, Perfect Sync, No Timing Errors, LQ Algorithm	(Optional) All UEs	20.1
Case 11, UMA, FR1, DL-TDOA, without $\Delta\tau$, Perfect Sync, No Timing Errors, RANSAC Algorithm	Outdoor UEs	1.5
Case 11, UMA, FR1, RTT, without $\Delta\tau$, Perfect Sync, No Timing Errors, RANSAC Algorithm	Indoor UEs	96
Case 14, UMI, FR1, RTT, With $\Delta\tau$, Perfect Sync, Timing Error = 1 ns, Likelihood Fusion Algorithm	(Optional) All UEs	7.3
Case 14, UMI, FR1, RTT, With $\Delta\tau$, Perfect Sync, Timing Error = 2 ns, Likelihood Fusion Algorithm	(Optional) All UEs	7.4
Case 14, UMI, FR1, RTT, With $\Delta\tau$, Perfect Sync, Timing Error = 5 ns, Likelihood Fusion Algorithm	(Optional) All UEs	7.6
Case 14, UMI, FR1, RTT, With $\Delta\tau$, Perfect Sync, Timing Error = 10 ns, Likelihood Fusion Algorithm	(Optional) All UEs	7.9

Horizontal Positioning Error		90%
Case 15, UMI, FR1,DL-TDOA, With $\Delta\tau$, Sync Error = 10, Timing Error = 0 ns, Likelihood Fusion Algorithm	(Optional) All UEs	9.3
Case 15, UMI, FR1,DL-TDOA, With $\Delta\tau$, Sync Error = 20, Timing Error = 0 ns, Likelihood Fusion Algorithm	(Optional) All UEs	9.3
Case 15, UMI, FR1,DL-TDOA, With $\Delta\tau$, Sync Error = 50, Timing Error = 0 ns, Likelihood Fusion Algorithm	(Optional) All UEs	12.5
Case 15, UMI, FR1, DL-TDOA, With $\Delta\tau$, Sync Error = 10, Timing Error = 2 ns, Likelihood Fusion Algorithm	(Optional) All UEs	9.3
Case 15, UMI, FR1,DL-TDOA, With $\Delta\tau$, Sync Error = 20, Timing Error = 2 ns, Likelihood Fusion Algorithm	(Optional) All UEs	9.3
Case 15, UMI, FR1,DL-TDOA, With $\Delta\tau$, Sync Error = 50, Timing Error = 2 ns, Likelihood Fusion Algorithm	(Optional) All UEs	12.5
Case 15, UMI, FR1, DL-TDOA, With $\Delta\tau$, Sync Error = 10, Timing Error = 10 ns, Likelihood Fusion Algorithm	(Optional) All UEs	9.3
Case 15, UMI, FR1, DL-TDOA, With $\Delta\tau$, Sync Error = 20, Timing Error = 10 ns, Likelihood Fusion Algorithm	(Optional) All UEs	9.3
Case 15, UMI, FR1, DL-TDOA, With $\Delta\tau$, Sync Error = 50, Timing Error = 10 ns, Likelihood Fusion Algorithm	(Optional) All UEs	12.5
Case 15, UMI, FR1,DL-TDOA, With $\Delta\tau$, Sync Error = 10, Timing Error = 0 ns, Likelihood Fusion Algorithm	(Optional) All UEs	9.3
Case 15, UMI, FR1,DL-TDOA, With $\Delta\tau$, Sync Error = 20, Timing Error = 0 ns, Likelihood Fusion Algorithm	(Optional) All UEs	9.3
Case 15, UMI, FR1,DL-TDOA, With $\Delta\tau$, Sync Error = 50, Timing Error = 0 ns, Likelihood Fusion Algorithm	(Optional) All UEs	12.5
Case 15, UMI, FR1, DL-TDOA, With $\Delta\tau$, Sync Error = 10, Timing Error = 2 ns, Likelihood Fusion Algorithm	(Optional) All UEs	9.3
Case 15, UMI, FR1,DL-TDOA, With $\Delta\tau$, Sync Error = 20, Timing Error = 2 ns, Likelihood Fusion Algorithm	(Optional) All UEs	9.3
Case 15, UMI, FR1,DL-TDOA, With $\Delta\tau$, Sync Error = 50, Timing Error = 2 ns, Likelihood Fusion Algorithm	(Optional) All UEs	12.5
Case 15, UMI, FR1, DL-TDOA, With $\Delta\tau$, Sync Error = 10, Timing Error = 10 ns, Likelihood Fusion Algorithm	(Optional) All UEs	9.3

Case 15, UMI, FR1, DL-TDOA, With $\Delta\tau$, Sync Error = 20, Timing Error = 10 ns, Likelihood Fusion Algorithm	(Optional) All UEs	9.3
Case 15, UMI, FR1, DL-TDOA, With $\Delta\tau$, Sync Error = 50, Timing Error = 10 ns, Likelihood Fusion Algorithm	(Optional) All UEs	12.5

Horizontal Positioning Error		90%
Case 16, UMI, FR1, RTT, Without $\Delta\tau$, Perfect Sync, Timing Error = 2 ns, Likelihood Fusion Algorithm	(Optional) All UEs	0.87
Case 16, UMI, FR1, RTT, Without $\Delta\tau$, Perfect Sync, Timing Error = 5 ns, Likelihood Fusion Algorithm	(Optional) All UEs	1.37
Case 16, UMI, FR1, RTT, Without $\Delta\tau$, Perfect Sync, Timing Error = 10 ns, Likelihood Fusion Algorithm	(Optional) All UEs	2.22
Case 16, UMI, FR1, RTT, Without $\Delta\tau$, Perfect Sync, Timing Error = 2 ns, Likelihood Fusion Algorithm	(Optional) All UEs	0.87
Case 16, UMI, FR1, RTT, Without $\Delta\tau$, Perfect Sync, Timing Error = 5 ns, Likelihood Fusion Algorithm	(Optional) All UEs	1.37
Case 16, UMI, FR1, RTT, Without $\Delta\tau$, Perfect Sync, Timing Error = 10 ns, Likelihood Fusion Algorithm	(Optional) All UEs	2.22
Case 17, UMI, FR1, DL-TDOA, Without $\Delta\tau$, Sync Error = 0, Timing Error = 0 ns, Likelihood Fusion Algorithm	(Optional) All UEs	0.61
Case 17, UMI, FR1, DL-TDOA, Without $\Delta\tau$, Sync Error = 0, Timing Error = 2 ns, Likelihood Fusion Algorithm	(Optional) All UEs	1
Case 17, UMI, FR1, DL-TDOA, Without $\Delta\tau$, Sync Error = 0, Timing Error = 10 ns, Likelihood Fusion Algorithm	(Optional) All UEs	2.3
Case 17, UMI, FR1, DL-TDOA, Without $\Delta\tau$, Sync Error = 0, Timing Error = 0 ns, Likelihood Fusion Algorithm	(Optional) All UEs	0.61
Case 17, UMI, FR1, DL-TDOA, Without $\Delta\tau$, Sync Error = 0, Timing Error = 2 ns, Likelihood Fusion Algorithm	(Optional) All UEs	1
Case 17, UMI, FR1, DL-TDOA, Without $\Delta\tau$, Sync Error = 0, Timing Error = 10 ns, Likelihood Fusion Algorithm	(Optional) All UEs	2.3

Case ID	Beam Pair	Tx T1	90%
Case 18 InF-SH, FR2, DL- TDOA	Earliest beam pair	0.0ns	0.01
		0.1ns	0.06
		0.2ns	0.13
		0.5ns	0.40
		1.0ns	0.96
		2.0ns	1.59
	Strongest beam pair	0.0ns	0.02
		0.1ns	0.11
		0.2ns	0.25
		0.5ns	0.94
		1.0ns	2.30
		2.0ns	5.19
Case 19 InF-DH, FR2, DL- TDOA	Earliest beam pair	0.0ns	0.02
		0.1ns	0.10
		0.2ns	0.24
		0.5ns	0.76
		1.0ns	2.10
		2.0ns	6.31
	Strongest beam pair	0.0ns	43.94
		0.1ns	36.56
		0.2ns	35.28
		0.5ns	44.16
		1.0ns	40.33
		2.0ns	46.31
Case 20 InH, FR2, DL- TDOA	Earliest beam pair	0.0ns	0.03
		0.1ns	0.31
		0.2ns	0.47
		0.5ns	1.16
		1.0ns	2.04
		2.0ns	4.11
	Strongest beam pair	0.0ns	0.21
		0.1ns	7.44
		0.2ns	8.22
		0.5ns	11.37
		1.0ns	14.94
		2.0ns	18.87
Case 21 UMi, FR2, DL- TDOA	Earliest beam pair	0.0ns	0.03
		0.1ns	0.13
		0.2ns	0.20
		0.5ns	0.38
		1.0ns	0.73
		2.0ns	1.38
		0.0ns	16.21

	Strongest beam pair	0.1ns	23.54
		0.2ns	16.59
		0.5ns	19.30
		1.0ns	14.27
		2.0ns	21.65

Table 8.1.1.10-2 captures observations based on NR positioning evaluations results for vertical location error.

Table 8.1.1.10-2: Rel.16 NR positioning – vertical accuracy performance summary

Vertical Positioning error		90%
Case 3, InF FR1 DH ISD20, 100MHz, RANSAC, DL TDOA, Variable UE heights	Convex UEs	20.6m
	(Optional) All UEs	38.9m
Case 3, InF FR1 DH ISD20, 100MHz, RANSAC, DL TDOA, Fixed UE heights	Convex UEs	18.44m
	(Optional) All UEs	22.98m
Case 4, InF FR1 SH ISD50, 100MHz, RANSAC, DL TDOA, Unequal gNBs heights, Variable UE heights	Convex UEs	1.89m
	(Optional) All UEs	2.63m
Case 4, InF FR1 SH ISD50, 100MHz, RANSAC, Unequal gNBs heights, DL TDOA, Unequal gNBs heights, Fixed UE heights	Convex UEs	0.9m
	(Optional) All UEs	1.34m

Vertical (Across All UEs)	Beam Pair	90%
Case 6 InF-SH FR2 3d mRTT	Earliest	0.084
Case 8 InF-SH FR2 3d mRTT	Earliest	0.041

8.1.1.11 Observations from source [18]

Table 8.1.1.11-1: Rel.16 NR positioning – horizontal accuracy performance summary from [18]

Simulation case (Horizontal Error)	Accuracy achieved @[90]%
Case 1- config ID 445 (FR1-InF DH)	≥10
Case 3- config ID 1112 (FR1-UMi)	3.24
Case 2- config ID 1011 (FR1-UMi with ATOA)	≥10

8.1.2 Physical layer latency analysis for Rel-16

8.1.2.1 Observations from source [4]

Summary of latency performance analysis is provided in Table 8.1.2.1-1.

Table 8.1.2.1-1: NR Rel.16 positioning – latency performance summary [4]

Description Evaluation Case	L1 Latency, ms	Commercial requirements [100]ms are met -Yes/No - If no, provide performance gaps	IIoT requirements of [10ms] are met - Yes/No. If no, provide performance gaps	IIoT requirements of [100]ms are met - Yes/No. If no, provide performance gaps
Case L1, DL-TDOA/DL- AoD/Multi-RTT w/ Gap request and PRS periodicity 20ms	51.5-66ms (1 samp.) 111.5- 126.5ms (4 samp. CSSF = 1) 171.5- 186ms (4 samp. CSSF = 2)	Yes (1 samp.) ≥11.5ms (4 samp. CSSF = 1) ≥71.5ms (4 samp. CSSF = 2)	≥41.5ms (1 samp.) ≥101.5ms (4 samp. CSSF = 1) ≥161.5ms (4 samp. CSSF = 2)	Yes (1 samp.) ≥11.5ms (4 samp. CSSF = 1) ≥71.5ms (4 samp. CSSF = 2)
Case L2, DL-TDOA/DL- AoD/Multi-RTT w/o Gap request and PRS periodicity 160ms	171.5- 178.5ms (1 samp.) 651.5- 658.5ms (4 samp. CSSF = 1)	No (1 samp.) No (4 samp. CSSF = 1)	No (1 samp.) No (4 samp. CSSF = 1)	No (1 samp.) No (4 samp. CSSF = 1)
Case L3, UL-TDOA/UL-AoA	6.5-26ms (1 samp.) 66.5- 86.5ms (4 samp)	Yes (1 samp.) Yes (4 samp.)	Yes/No (1 samp.) ≥56.5ms (4 samp.)	Yes (1 samp.) Yes (4 samp.)
Case L4, DL E-CID	8.5-15ms	Yes	Yes/No	Yes
Case L5, UL E-CID	6-26ms	Yes	Yes/No	Yes
Case L6, UE-based DL- TDOA/DL-AoD w/ gap request t and PRS periodicity 20ms	51-58.5ms (1 samp.)	Yes	≥41ms	Yes

8.1.2.2 Observations from source [7]

Summary of latency performance analysis is provided in Table 8.1.2.2-1.

Table 8.1.2.2-1: NR Rel.16 positioning – latency performance summary [7]

Description Evaluation Case	L1 Latency, ms
Case PHY-L1, UE-A, DL- TDOA, FR1, FDD	106.23
Case PHY-L1, UE-A, DL- TDOA, FR2, FDD	667.87
Case PHY-L2, UE-B, DL- TDOA, FR1, FDD	106.30
Case PHY-L2, UE-B, DL- TDOA, FR2, FDD	667.82
Case PHY-L3, UE-A, DL- ECID, FR1, FDD	10.43
Case PHY-L3, UE-A, DL- ECID, FR2, FDD	10.64

8.1.2.3 Observations from source [8]

Summary of latency performance analysis is provided in Table 8.1.2.3-1.

Table 8.1.2.3-1: NR Rel.16 positioning - latency performance summary [8]

Description Evaluation Case	L1 Latency, ms	Commercial requirements [100]ms are met - Yes/No - If No, provide performance gaps	IIoT requirements of [10ms] are met - Yes/No. If No, provide performance gaps	IIoT requirements of [100]ms are met - Yes/No. If No, provide performance gaps
Case 1, 15kHz, FR1, DL-TDOA	51.5	Yes	No (41.5ms gaps)	Yes
Case 2, 15kHz, FR1, UL-TDOA	5	Yes	Yes	Yes

8.1.2.4 Observations from source [13]

Table 8.1.2.4-1: NR Rel.16 positioning - latency performance summary [13]

Description Evaluation Case	L1 Latency, ms
Case 1, DL-TDOA/DL-AoD, FR1	[44.35 – 10500]
Case 2, DL-TDOA/DL-AoD, FR2	[35.08 – 2118.93]
Case 3, UL-TDOA/UL-AoA, FR1	[2.78 – 81928.5]

8.1.2.5 Observations from source [11]

A summary of the physical layer latency performance analysis for the DL-based positioning methods is provided in Table 8.1.2.5-1.

Table 8.1.2.5-1: NR Rel.16 positioning - latency performance summary [11]

Description Evaluation Case	L1 Latency ¹ , ms
Case ID: 1, Scenario: UE-Assisted Positioning with MG configuration, Frequency Band: FR1/FR2, Technique: R.16 DL-TDOA/R.16 DL-AoD	[38 - 235.6]: 30 kHz SCS
	[35 - 229.6]: 120 kHz SCS
Case ID: 2, Scenario: UE-Assisted Positioning without MG configuration, Frequency Band: FR1/FR2, Technique: R.16 DL-TDO/ R.16 DL-AoD	[17 - 5147.8]: 30 kHz SCS
	[15.5 - 5144.8]: 120 kHz SCS
Case ID: 3, Scenario: UE-based Positioning with MG configuration, Frequency Band: FR1/FR2, Technique: R.16 DL-TDOA/R.16 DL-AoD	[29 - 207.8]: 30 kHz SCS
	[27.5 - 204.8]: 120 kHz SCS
Case ID: 4, Scenario: UE-based Positioning without MG configuration, Frequency Band: FR1/FR2, Technique: R.16 DL-TDOA/R.16 DL-AoD	[8 – 5120]: 120 kHz SCS
Notes: 1: The presented L1 latency value ranges correspond to the minimum and cautious estimates. Due to the assumptions of a single DL-PRS occasion, this may not correspond to an accurate positioning measurement and serves a guideline for the achievable physical layer latency. The cautious estimate is not intended to indicate the physical layer latency upper bound.	

8.1.2.6 Observations from source [5]

Summary of latency performance analysis is provided in Table 8.1.2.6-1.

Table 8.1.2.6-1: NR Rel.16 positioning – latency performance summary [5]

Description Evaluation Case	L1 Latency ms	Commercial requirements [100]ms are met - Yes/No - If no, provide performance gaps	IIoT requirements of [10ms] are met - Yes/No. If no, provide performance gaps	IIoT requirements of [100]ms are met - Yes/No. If no, provide performance gaps
[Case 1], [IIoT/ Commercial], [Frequency Band], [DL- TDOA/AoD],[UE-A]	64ms~		54ms~	
[Case 1-1], [IIoT/ Commercial], [Frequency Band], [DL- TDOA/AoD],[UE-A], [idle,inactive]	85.3ms~ or 104ms~		75.3ms~ or 94ms~	
[Case 2], [IIoT/ Commercial], [Frequency Band], [DL- TDOA/AoD],[UE-B] Source [Network]/Destination [Network]	66 ms ~		56ms~	
[Case 3], [IIoT/ Commercial], [Frequency Band], [DL- TDOA/AoD],[UE-B] Source [UE]/Destination [UE]	55.5ms~		45.5ms~	
[Case 4], [IIoT/ Commercial], [Frequency Band], [UL-TDOA/UL- AoA], [periodic SRS]	30.5ms~		20.5ms~	
[Case 5], [IIoT/ Commercial], [Frequency Band], [UL-TDOA/UL- AoA], [A- SRS]	11ms~		1ms~	
[Case 6], [IIoT/ Commercial], [Frequency Band], [Multi-RTT]	94.5+ $T_{Align_DL_UL}$ ~		84.5+ $T_{Align_DL_UL}$ ~	

8.1.2.7 Observations from source [12]

Summary of latency performance analysis is provided in Table 8.1.2.7-1.

Table 8.1.2.7-1: NR Rel.16 positioning – latency performance summary [12]

Description Evaluation Case	L1 Latency, ms
Case1, DL-TDOA,FR1	54.125
Case2, UL-TDOA,FR1	23.25
Case3, UE- based method,FR1	54.125
Case4, DL-TDOA,FR2	52.56
Case5, UL-TDOA,FR2	23.125
Case6, UE- based method,FR2	52.56

8.1.2.8 Observations from source [10]

Summary of latency performance analysis is provided in Table 8.1.2.8-1.

Table 8.1.2.8-1: NR Rel.16 positioning – latency performance summary[10]

Description Evaluation Case	L1 Latency, ms
Case 1, InF, FR1, R.16 DL-TDOA/DL-AoD	4.5714 (L1 components) + [36] (L2/L3 components) + 88.5 (DL PRS processing) = 129.07 ms (total)
Case 2, InF, FR1, R.16 UL-TDOA/UL-AoA	2.7678 (L1 components) + [16] (L2/L3 components) = 18.7678 (total)
Case 3, InF, FR1, R.16 Multi-RTT	7.3393 (L1 components) + [45] (L2/L3 components) + 88.5 (DL PRS processing) = 140.8393 (total)

8.1.2.9 Observations from source [16]

The latency analysis for each case is summarized in the following table:

Table 8.1.2.9-1: NR Rel.16 positioning – latency performance summary [16]

Description Evaluation Case	L1 Latency, ms
Latency analysis for UE-assisted DL methods (Case 1)	33
UE-based DL methods (Case 2)	22-72
UE-assisted UL methods (Case 3)	12
UE-assisted DL+UL methods (Case 4)	45

8.1.2.10 Observations from source [17]

Summary of latency performance analysis is provided in Table 8.1.2.10-1.

Table 8.1.2.10-1: NR Rel.16 positioning – latency performance summary [17]

NR Rel-16 Scenario	L1-layer Latency Expected Range (ms)
UE-Assisted DL-only Positioning, RRC Connected State	57 - 823
UE-based DL-only Positioning, RRC Inactive State, External Client	35.3 - 803.5
UE-based DL-only Positioning, RRC Connected State, UE Internal-client	46 - 811
UE-based DL-only Positioning, RRC Inactive State, UE internal-client	8 - 780
UE-Assisted MRTT Positioning, RRC Connected State	59 - 823

8.1.2.11 Observations from source [15]

Summary of latency performance analysis is provided in Table 8.1.2.11-1.

Table 8.1.2.11-1: NR positioning – latency analysis [15]

Description Evaluation Case	Assumptions	L1 Latency, ms (including preparation/processi ng time at higher layer)	L1 Latency, ms (excluding preparation/processi ng time at higher layer)
Case 1, DL- TDOA, DL-AOD [NW initiated, UE- A]	FR1, 15kHz # of symbols for PUSCH: 1~14 OS # of symbols for PDSCH: 2~14 OS # of symbols for SRS: 2~12 OS	For UE capability-1: 62.97 ms ~ 297.11ms For UE capability-2: 61.17 ms ~ 293.68 ms	For UE capability-1: 23.97ms ~ 249.11ms For UE capability-2: 22.17ms ~ 245.68ms
Case 2, DL- TDOA, DL-AOD [UE initiated, UE- A]	Periodicity and offset for PUCCH: 2 OS ~ 80 slot The length of symbols for PUCCH: 1 OS~ 14 OS	For UE capability-1: 55.26ms ~ 284.83ms For UE capability-2: 53.82ms ~ 282.97ms	For UE capability-1: 23.26ms ~ 247.33ms For UE capability-2: 21.82ms ~ 245.47ms
Case 3, UL- TDOA, UL-AOA [NW initiated, UE- A]	Slot for PDCCH Monitoring configured as periodicity and offset is 1slot. The first symbol(s) for PDCCH monitoring in the slots is zero	For UE capability-1: 14.78 ms ~ 20.14 ms For UE capability-2: 14.42 ms ~ 19.57 ms	For UE capability-1: 0.78 ms ~ 2.64ms For UE capability-2: 0.42ms ~ 2.07ms
Case 4, Multi-RTT [NW initiated, UE- A]	# of symbols for CORESET: 1 OS ~3 OS -Uplink switching gap is not configured. -No BWP switching	For UE capability-1: 77.75 ms ~314.75 ms For UE capability-2: 75.59 ms ~ 311.75 ms	For UE capability-1: 24.75 ms ~ 251.75 ms For UE capability-2: 22.59 ms ~ 248.75 ms
Case 5, E-CID [NW initiated, UE- A]	-No overlapping symbols of the PUCCH and the scheduled PUSCH -No overlapping symbols of the scheduling PDCCH and the scheduled PDSCH *Note: The maximum latency for PDSCH/PUSCH transmission is assumed as one slot excluding preparation time. Total values may change when the information size related with LPP message is changed. *Note: According to scheduling request configuration and UL grant configuration, the total values may change. For example, larger periodicity for SR and/or PDCCH monitoring periodicity are set.	For UE capability-1: 28.41ms ~ 116.55 ms For UE capability-2: 27.33 ms ~ 115.05 ms	For UE capability-1: 2.41 ms ~ 85.55 ms For UE capability-2: 1.33 ms ~ 84.05 ms

8.1.3 Higher layer latency analysis for Rel-16

8.1.3.1 Latency analysis for DL-TDOA/DL-AoD

Referred to [27], Figure 8.1.3.1-1 shows the messaging between the LMF, the AMF, the gNBs and the UE to perform DL-TDOA and DL-AoD procedure.

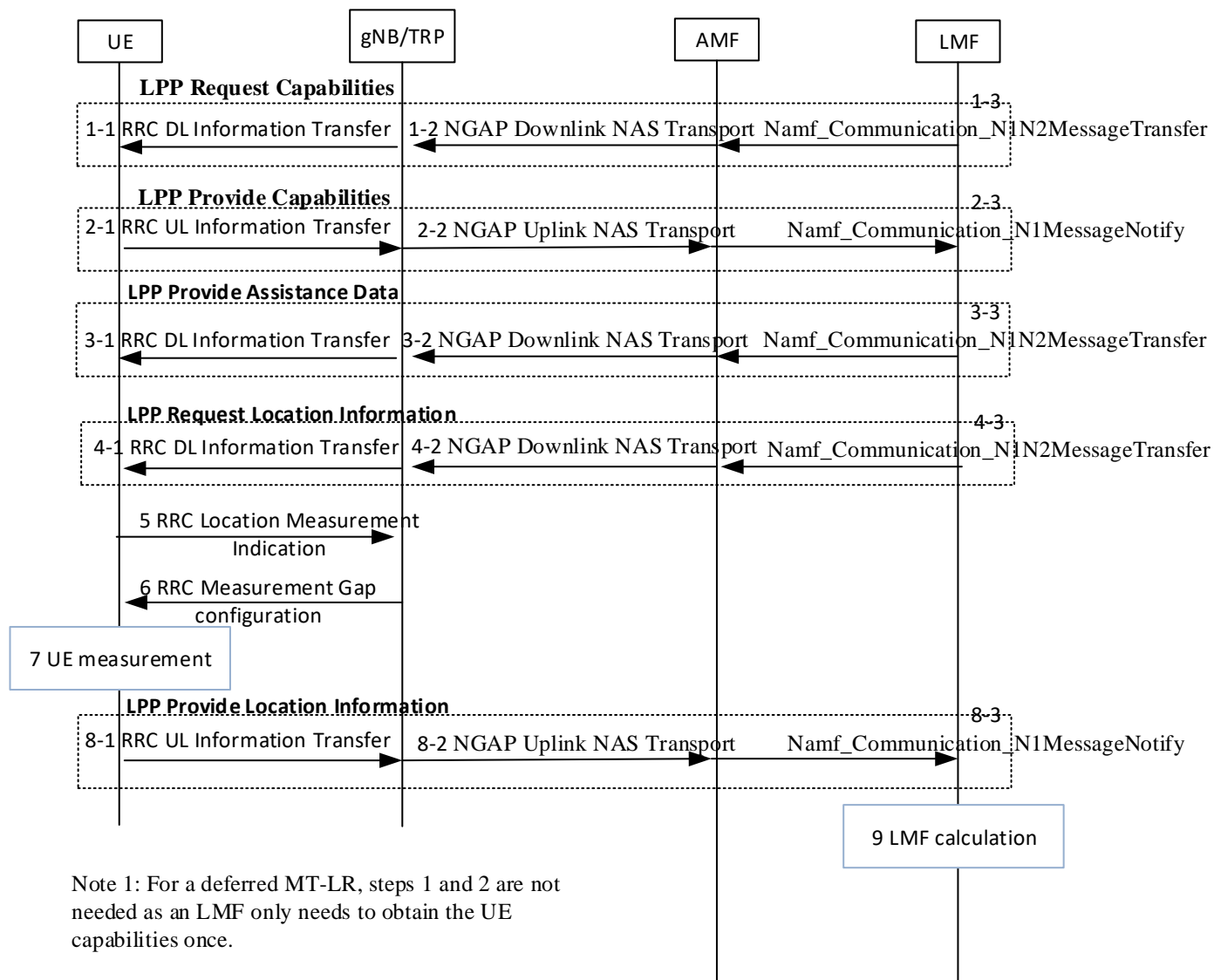


Figure 8.1.3.1-1: DL-TDOA/DL-AoD positioning procedure

The latency performance analysis for UE assisted DL-TDOA and DL-AoD are provided in table 8.1.3.1-1.

Table 8.1.3.1-1: Latency performance analysis for UE assisted DL-TDOA and DL-AoD

Step	Delay Value [ms]	Description of Latency Component
Step 1 LPP Request capabilities	18-34.5	Processing delays: 14 ms <ul style="list-style-type: none"> - UE: $T_{UEProc-RRCDLInfo}$ - gNB: $T_{gNBProc-NAS/LPP}$ - AMF: $T_{AMFProc}$ - LMF: $T_{LMFProc}$ Signalling delay: 4-20.5ms <ul style="list-style-type: none"> - UE-gNB: T_{UE-gNB} - gNB-AMF: $T_{gNB-AMF}$ - AMF-LMF: $T_{AMF-LMF}$ Note 1: the LPP capability processing delay is counted together in response message.
Step 2 LPP Provide Capabilities	25-54.5	Processing delays: 21-34 ms <ul style="list-style-type: none"> - UE: <ul style="list-style-type: none"> $T_{UEProc-RRCDLInfo}$ $T_{UEProc-LPPCapab}$ - gNB: $T_{gNBProc-NAS/LPP}$ - AMF: $T_{AMFProc}$ - LMF: $T_{LMFProc}$ Signalling delay: 4-20.5 ms <ul style="list-style-type: none"> - UE-gNB: T_{UE-gNB} - gNB-AMF: $T_{gNB-AMF}$ - AMF-LMF: $T_{AMF-LMF}$
Step 3 LPP Provide Assistance Data	28-44.5	Processing delays: 24 ms <ul style="list-style-type: none"> - UE: <ul style="list-style-type: none"> $T_{UEProc-RRCDLInfo}$ $T_{UEProc-LPPAssi}$ - gNB: $T_{gNBProc-NAS/LPP}$ - AMF: $T_{AMFProc}$ - LMF: $T_{LMFProc}$ Signalling delay: 4-20.5 ms <ul style="list-style-type: none"> - UE-gNB: T_{UE-gNB} - gNB-AMF: $T_{gNB-AMF}$ - AMF-LMF: $T_{AMF-LMF}$
Step 4 LPP Request Location Information	23-39.5	Processing delays: 19 ms <ul style="list-style-type: none"> - UE: <ul style="list-style-type: none"> $T_{UEProc-RRCDLInfo}$ $T_{UEProc-LPPLocationRe}$ - gNB: $T_{gNBProc-NAS/LPP}$ - AMF: $T_{AMFProc}$ - LMF: $T_{LMFProc}$ Signalling delay: 4-20.5ms <ul style="list-style-type: none"> - UE-gNB: T_{UE-gNB} - gNB-AMF: $T_{gNB-AMF}$ - AMF-LMF: $T_{AMF-LMF}$
Step 5 RRC Location Measurement Indication	5-8.5	Processing delays: 5-8 ms <ul style="list-style-type: none"> - UE: $T_{UEProc-RRCLocationMeas}$ - gNB: $T_{gNBProc-RRC}$ Signalling delay: 0-0.5ms <ul style="list-style-type: none"> - UE-gNB: T_{UE-gNB}
Step 6 RRC Measurement Gap configuration	13-13.5	Processing delays: 13 ms <ul style="list-style-type: none"> - UE: $T_{UEProc-RRCreconf}$ - gNB: $T_{gNBProc-RRC}$ Signalling delay: 0-0.5ms <ul style="list-style-type: none"> - UE-gNB: T_{UE-gNB}
Step 7 DL PRS measurement	88.5	$T_{DL-Meas}$

Step	Delay Value [ms]	Description of Latency Component
Step 8 LPP Provide Location Information	20-39.5	Processing delays: 16-19 ms - UE: - $T_{\text{UEProc-RRCUInfo}}$ - $T_{\text{UEProc-LPPLocationRe}}$ - gNB: $T_{\text{gNBProc-NAS/LPP}}$ - AMF: T_{AMFProc} - LMF: T_{LMFProc} Signalling delay: 4-20.5 ms - UE-gNB: $T_{\text{UE-gNB}}$ - gNB-AMF: $T_{\text{gNB-AMF}}$ - AMF-LMF: $T_{\text{AMF-LMF}}$
Step 9 LMF calculation	2-30	$T_{\text{LMF-Calc}}$
Total values	222.5-353	

8.1.3.2 Latency analysis for UL-TDOA/UL-AoA

Referred to [27], Figure 8.1.3.2-1 shows the messaging between the LMF, the AMF, the gNBs and the UE to perform UL-TDOA and UL-AoA procedure.

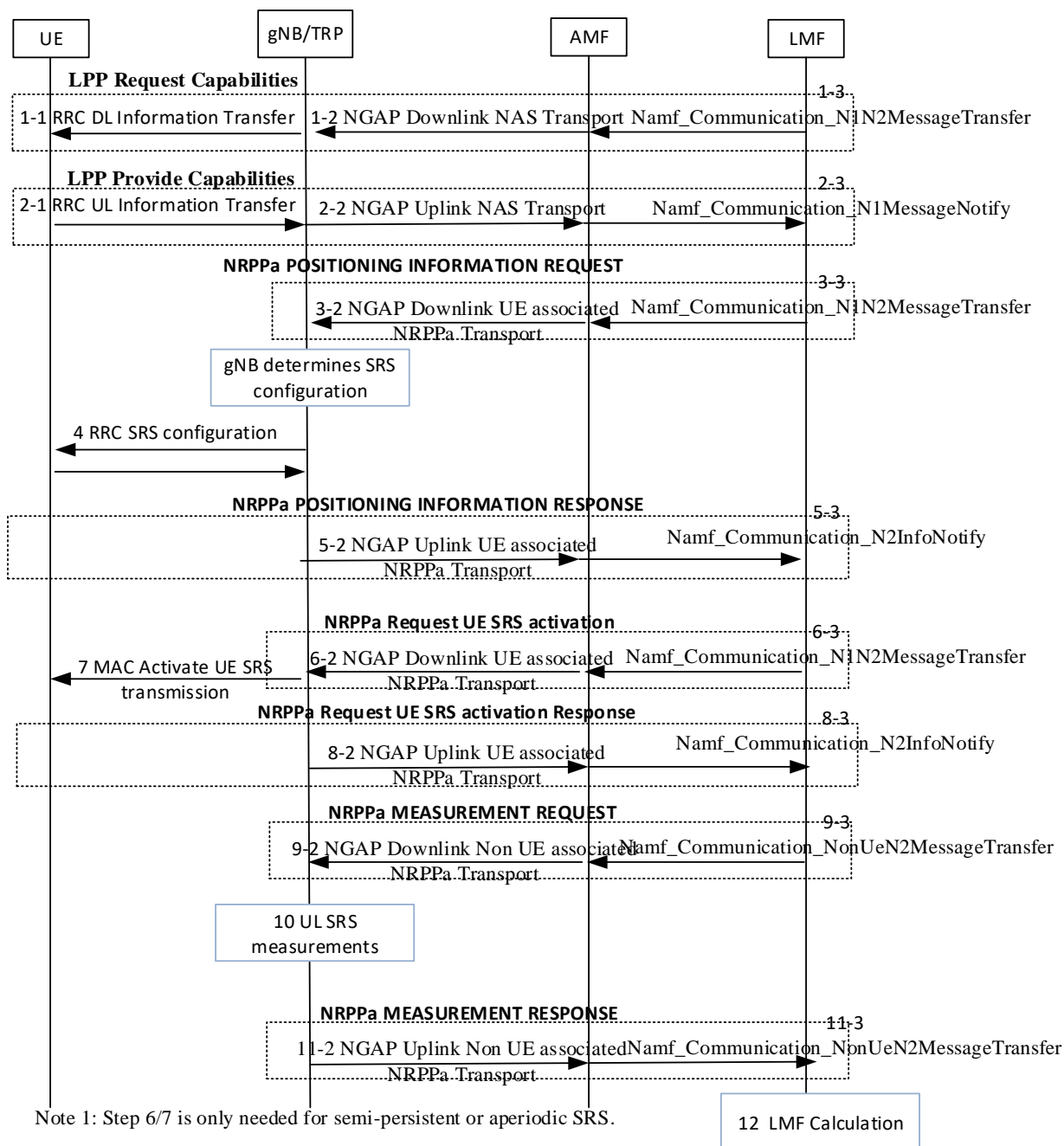


Figure 8.1.3.2-1: UL-TDOA/UL-AoA positioning procedure

The latency performance analysis for UE assisted UL-TDOA and UL-AoA are provided in table 8.1.3.2-1.

Table 8.1.3.2-1: Latency performance analysis for UE assisted UL-TDOA and UL-AoA

Step	Delay Value [ms]	Description of Latency Component
Step 1 LPP Request capabilities	18-34.5	<p>Processing delays: 14 ms</p> <ul style="list-style-type: none"> - UE: $T_{UEProc-RRCDLInfo}$ - gNB: $T_{gNBProc-NAS/LPP}$ - AMF: $T_{AMFProc}$ - LMF: $T_{LMFProc}$ <p>Signalling delay: 4-20.5ms</p> <ul style="list-style-type: none"> - UE-gNB: T_{UE-gNB} - gNB-AMF: $T_{gNB-AMF}$ - AMF-LMF: $T_{AMF-LMF}$ <p>Note 1: the LPP capability processing delay is counted together in response message. Note 2: Should not be counted if the LMF does not need the capability, e.g. only use Rel-15 SRS for UL positioning.</p>
Step 2 LPP Provide Capabilities	25-54.5	<p>Processing delays: 21-34 ms</p> <ul style="list-style-type: none"> - UE: <ul style="list-style-type: none"> $T_{UEProc-RRCDLInfo}$ $T_{UEProc-LPPCapab}$ - gNB: $T_{gNBProc-NAS/LPP}$ - AMF: $T_{AMFProc}$ - LMF: $T_{LMFProc}$ <p>Signalling delay: 4-20.5 ms</p> <ul style="list-style-type: none"> - UE-gNB: T_{UE-gNB} - gNB-AMF: $T_{gNB-AMF}$ - AMF-LMF: $T_{AMF-LMF}$
Step 3 NRPPa POSITIONING INFORMATION REQUEST	13-29	<p>Processing delays: 9 ms</p> <ul style="list-style-type: none"> - gNB: $T_{gNBProc-NRPPa}$ - AMF: $T_{AMFProc}$ - LMF: $T_{LMFProc}$ <p>Signalling delay: 4-20 ms</p> <ul style="list-style-type: none"> - gNB-AMF: $T_{gNB-AMF}$ - AMF-LMF: $T_{AMF-LMF}$
Step 4 RRC SRS configuration	13-13.5	<p>Processing delays: 13 ms</p> <ul style="list-style-type: none"> - UE: $T_{UEProc-RRReconf}$ - gNB: $T_{gNBProc-RR}$ <p>Signalling delay: 0-0.5ms</p> <ul style="list-style-type: none"> - UE-gNB: T_{UE-gNB} <p>Note 3: Should not be counted if the SRS configuration has been configured before the procedure.</p>
Step 5 NRPPa POSITIONING INFORMATION RESPONSE	13-29	<p>Processing delays: 9 ms</p> <ul style="list-style-type: none"> - gNB: $T_{gNBProc-NRPPa}$ - AMF: $T_{AMFProc}$ - LMF: $T_{LMFProc}$ <p>Signalling delay: 4-20 ms</p> <ul style="list-style-type: none"> - gNB-AMF: $T_{gNB-AMF}$ - AMF-LMF: $T_{AMF-LMF}$
Step 6 NRPPa Request UE SRS activation	13-29	<p>Processing delays: 9 ms</p> <ul style="list-style-type: none"> - gNB: $T_{gNBProc-NRPPa}$ - AMF: $T_{AMFProc}$ - LMF: $T_{LMFProc}$ <p>Signalling delay: 4-20 ms</p> <ul style="list-style-type: none"> - gNB-AMF: $T_{gNB-AMF}$ - AMF-LMF: $T_{AMF-LMF}$ <p>Note 4: Should not be counted if the periodic SRS is used.</p>
Step 7 MAC Activate UE SRS transmission	1-3.5	<p>Processing delays: 1-3ms</p> <ul style="list-style-type: none"> - UE: $T_{UEProc-MAC-SRAct}$ <p>Signalling delay: 0-0.5ms</p> <ul style="list-style-type: none"> - UE-gNB: T_{UE-gNB} <p>Note 5: Should not be counted if the periodic or aperiodic SRS is used.</p>

Step	Delay Value [ms]	Description of Latency Component
Step 8 NRPPa Request UE SRS activate Response	13-29	Processing delays: 9 ms - gNB: $T_{\text{gNBProc-NRPPa}}$ - AMF: T_{AMFProc} - LMF: T_{LMFProc} Signalling delay: 4-20 ms - gNB-AMF: $T_{\text{gNB-AMF}}$ - AMF-LMF: $T_{\text{AMF-LMF}}$ Note 6: Should not be counted if the periodic SRS is used.
Step 9 NRPPa MEASUREMENT REQUEST	13-29	Processing delays: 9 ms - gNB: $T_{\text{gNBProc-NRPPa}}$ - AMF: T_{AMFProc} - LMF: T_{LMFProc} Signalling delay: 4-20 ms - gNB-AMF: $T_{\text{gNB-AMF}}$ - AMF-LMF: $T_{\text{AMF-LMF}}$
Step 10 UL SRS measurement	12	$T_{\text{UL-Meas}}$
Step 11 NRPPa MEASUREMENT RESPONSE	13-29	Processing delays: 9 ms - gNB: $T_{\text{gNBProc-NRPPa}}$ - AMF: T_{AMFProc} - LMF: T_{LMFProc} Signalling delay: 4-20 ms - gNB-AMF: $T_{\text{gNB-AMF}}$ - AMF-LMF: $T_{\text{AMF-LMF}}$
Step 12 LMF calculation	2-30	$T_{\text{LMF-Calc}}$
Total values	149-322	

8.1.3.3 Latency analysis for Multi-RTT

Referred to [27], Figure 8.1.3.3-1 shows the messaging between the LMF, the AMF, the gNBs and the UE to perform Multi-RTT procedure.

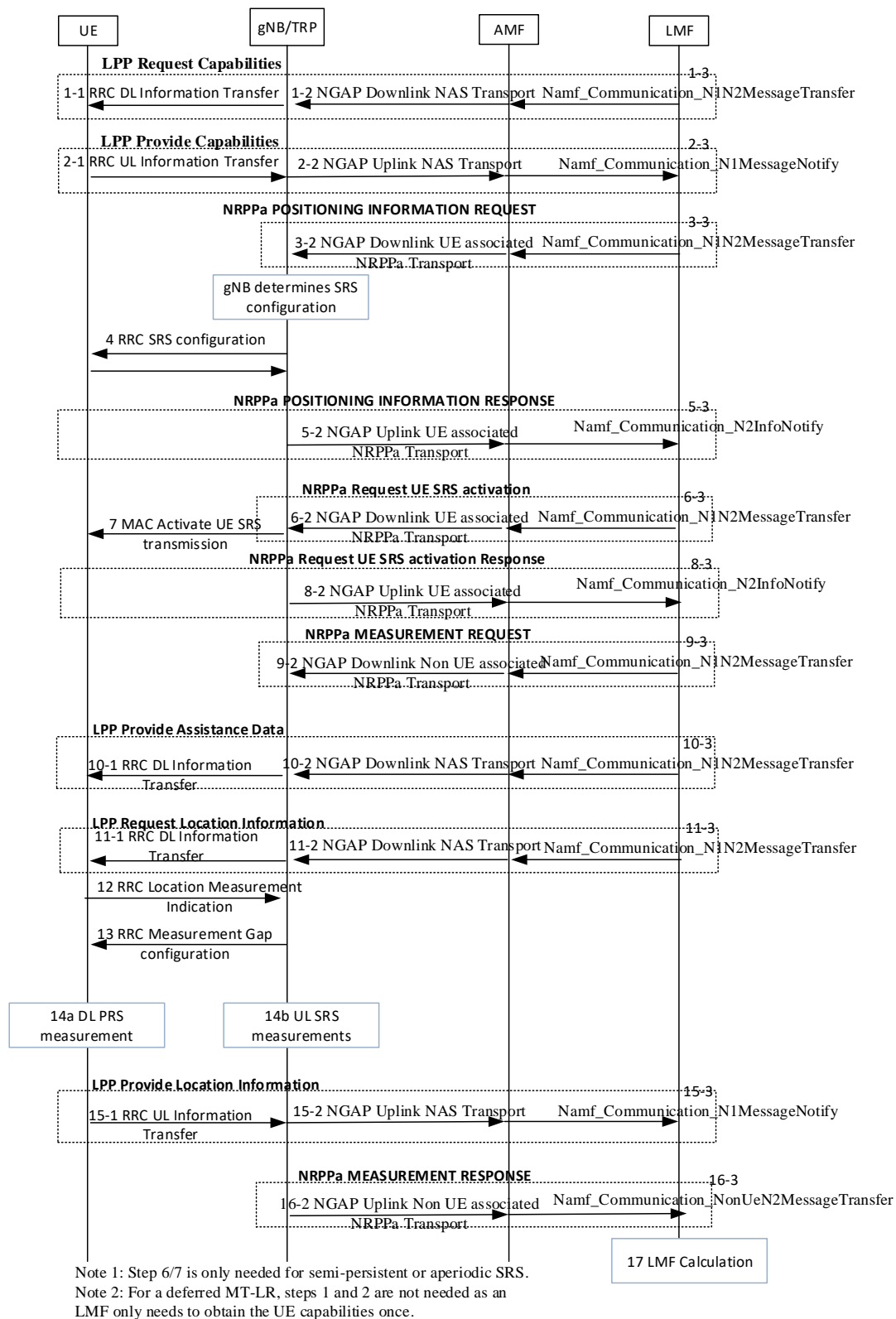


Figure 8.1.3.3-1: Multi-RTT positioning procedure

The latency performance analysis for UE assisted Multi-RTT are provided in table 8.1.3.3-1.

Table 8.1.3.3-1: Latency performance analysis for UE assisted Multi-RTT

Step	Delay Value [ms]	Description of Latency Component
Step 1 LPP Request capabilities	18-34.5	Processing delays: 14 ms <ul style="list-style-type: none"> - UE: $T_{UEProc-RRCDLInfo}$ - gNB: $T_{gNBProc-NAS/LPP}$ - AMF: $T_{AMFProc}$ - LMF: $T_{LMFProc}$ Signalling delay: 4-20.5ms <ul style="list-style-type: none"> - UE-gNB: T_{UE-gNB} - gNB-AMF: $T_{gNB-AMF}$ - AMF-LMF: $T_{AMF-LMF}$ Note 1: the LPP capability processing delay is counted together in response message.
Step 2 LPP Provide Capabilities	25-54.5	Processing delays: 21-34 ms <ul style="list-style-type: none"> - UE: <ul style="list-style-type: none"> $T_{UEProc-RRCDLInfo}$ $T_{UEProc-LPPCapab}$ - gNB: $T_{gNBProc-NAS/LPP}$ - AMF: $T_{AMFProc}$ - LMF: $T_{LMFProc}$ Signalling delay: 4-20.5 ms <ul style="list-style-type: none"> - UE-gNB: T_{UE-gNB} - gNB-AMF: $T_{gNB-AMF}$ - AMF-LMF: $T_{AMF-LMF}$
Step 3 NRPPa POSITIONING INFORMATION REQUEST	13-29	Processing delays: 9 ms <ul style="list-style-type: none"> - gNB: $T_{gNBProc-NRPPa}$ - AMF: $T_{AMFProc}$ - LMF: $T_{LMFProc}$ Signalling delay: 4-20 ms <ul style="list-style-type: none"> - gNB-AMF: $T_{gNB-AMF}$ - AMF-LMF: $T_{AMF-LMF}$
Step 4 RRC SRS configuration	13-13.5	Processing delays: 13 ms <ul style="list-style-type: none"> - UE: $T_{UEProc-RRCreconf}$ - gNB: $T_{gNBProc-RRC}$ Signalling delay: 0-0.5ms <ul style="list-style-type: none"> - UE-gNB: T_{UE-gNB} Note 2: Should not be counted if the SRS configuration has been configured before the procedure.
Step 5 NRPPa POSITIONING INFORMATION RESPONSE	13-29	Processing delays: 9 ms <ul style="list-style-type: none"> - gNB: $T_{gNBProc-NRPPa}$ - AMF: $T_{AMFProc}$ - LMF: $T_{LMFProc}$ Signalling delay: 4-20 ms <ul style="list-style-type: none"> - gNB-AMF: $T_{gNB-AMF}$ - AMF-LMF: $T_{AMF-LMF}$
Step 6 NRPPa Request UE SRS activation	13-29	Processing delays: 9 ms <ul style="list-style-type: none"> - gNB: $T_{gNBProc-NRPPa}$ - AMF: $T_{AMFProc}$ - LMF: $T_{LMFProc}$ Signalling delay: 4-20 ms <ul style="list-style-type: none"> - gNB-AMF: $T_{gNB-AMF}$ - AMF-LMF: $T_{AMF-LMF}$ Note 3: Should not be counted if the periodic SRS is used.
Step 7 MAC Activate UE SRS transmission	1-3.5	Processing delays: 1-3ms <ul style="list-style-type: none"> - UE: $T_{UEProc-MAC-SRSAct}$ Signalling delay: 0-0.5ms <ul style="list-style-type: none"> - UE-gNB: T_{UE-gNB} Note 4: Should not be counted if the periodic or aperiodic SRS is used.
Step 8 NRPPa Request UE SRS activate Response	13-29	Processing delays: 9 ms <ul style="list-style-type: none"> - gNB: $T_{gNBProc-NRPPa}$ - AMF: $T_{AMFProc}$ - LMF: $T_{LMFProc}$ Signalling delay: 4-20 ms <ul style="list-style-type: none"> - gNB-AMF: $T_{gNB-AMF}$ - AMF-LMF: $T_{AMF-LMF}$ Note 5: Should not be counted if the periodic SRS is used.

Step	Delay Value [ms]	Description of Latency Component
Step 9 NRPPa MEASUREMENT REQUEST	13-29	Processing delays: 9 ms - gNB: $T_{\text{gNBProc-NRPPa}}$ - AMF: T_{AMFProc} - LMF: T_{LMFProc} Signalling delay: 4-20 ms - gNB-AMF: $T_{\text{gNB-AMF}}$ - AMF-LMF: $T_{\text{AMF-LMF}}$ Note 6: Step 9 (NRPPa Measurement Request) can be performed in parallel with Steps 10/11 (LPP signalling). Hence, only the bigger number of the two procedures are considered (i.e., the latency for NRPPa Measurement Request is not counted in the summation).
Step 10 LPP Provide Assistance Data	28-44.5	Processing delays: 24 ms - UE: - $T_{\text{UEProc-RRCDLInfo}}$ - $T_{\text{UEProc-LPPAssi}}$ - gNB: $T_{\text{gNBProc-NAS/LPP}}$ - AMF: T_{AMFProc} - LMF: T_{LMFProc} Signalling delay: 4-20.5 ms - UE-gNB: $T_{\text{UE-gNB}}$ - gNB-AMF: $T_{\text{gNB-AMF}}$ - AMF-LMF: $T_{\text{AMF-LMF}}$
Step 11 LPP Request Location Information	23-39.5	Processing delays: 19 ms - UE: - $T_{\text{UEProc-RRCDLInfo}}$ - $T_{\text{UEProc-LPPLocationRe}}$ - gNB: $T_{\text{gNBProc-NAS/LPP}}$ - AMF: T_{AMFProc} - LMF: T_{LMFProc} Signalling delay: 4-20.5ms - UE-gNB: $T_{\text{UE-gNB}}$ - gNB-AMF: $T_{\text{gNB-AMF}}$ - AMF-LMF: $T_{\text{AMF-LMF}}$
Step 12 RRC Location Measurement Indication	5-8.5	Processing delays: 5-8 ms - UE: $T_{\text{UEProc-RRCLocationMeas}}$ - gNB: $T_{\text{gNBProc-RRC}}$ Signalling delay: 0-0.5ms - UE-gNB: $T_{\text{UE-gNB}}$
Step 13 RRC Measurement Gap configuration	13-13.5	Processing delays: 13 ms - UE: $T_{\text{UEProc-RRCreconf}}$ - gNB: $T_{\text{gNBProc-RRC}}$ Signalling delay: 0-0.5ms - UE-gNB: $T_{\text{UE-gNB}}$
Step 14 a DL PRS measurement	88.5	$T_{\text{DL-Meas}}$
Step 14 b UL SRS measurement	12	$T_{\text{UL-Meas}}$ Note 7: Step 14b (UL SRS measurement) can be performed in parallel with Step 14 a (DL PRS measurement). Hence, only the bigger number of the two procedures are considered (i.e., the latency for UL SRS measurement is not counted in the summation).
Step 15 LPP Provide Location Information	20-39.5	Processing delays: 16-19 ms - UE: - $T_{\text{UEProc-RRCUInfo}}$ - $T_{\text{UEProc-LPPLocationRe}}$ - gNB: $T_{\text{gNBProc-NAS/LPP}}$ - AMF: T_{AMFProc} - LMF: T_{LMFProc} Signalling delay: 4-20.5 ms - UE-gNB: $T_{\text{UE-gNB}}$ - gNB-AMF: $T_{\text{gNB-AMF}}$ - AMF-LMF: $T_{\text{AMF-LMF}}$

Step	Delay Value [ms]	Description of Latency Component
Step 16 NRPPa MEASUREMENT RESPONSE	13-29	Processing delays: 9 ms - gNB: $T_{\text{gNBProc-NRPPa}}$ - AMF: T_{AMFProc} - LMF: T_{LMFProc} Signalling delay: 4-20 ms - gNB-AMF: $T_{\text{gNB-AMF}}$ - AMF-LMF: $T_{\text{AMF-LMF}}$ Note 9: Step 16 (NRPPa Measurement Response) can be performed in parallel with Step 15 (LPP Provide Location Information). The UL- and DL- measurements are made concurrently, hence the results are send at about the same time. Only the bigger number of the two procedures need to be considered (i.e., the latency for NRPPa Measurement Response is not counted in the summation).
Step 17 LMF calculation	2-30	$T_{\text{LMF-Calc}}$
Total values	288.5-486	

8.1.3.4 Latency analysis for NR E-CID

Referred to [27], Figure 8.1.3.4-1 shows the messaging between the LMF, the AMF, the gNBs and the UE to perform Downlink NR E-CID procedure.

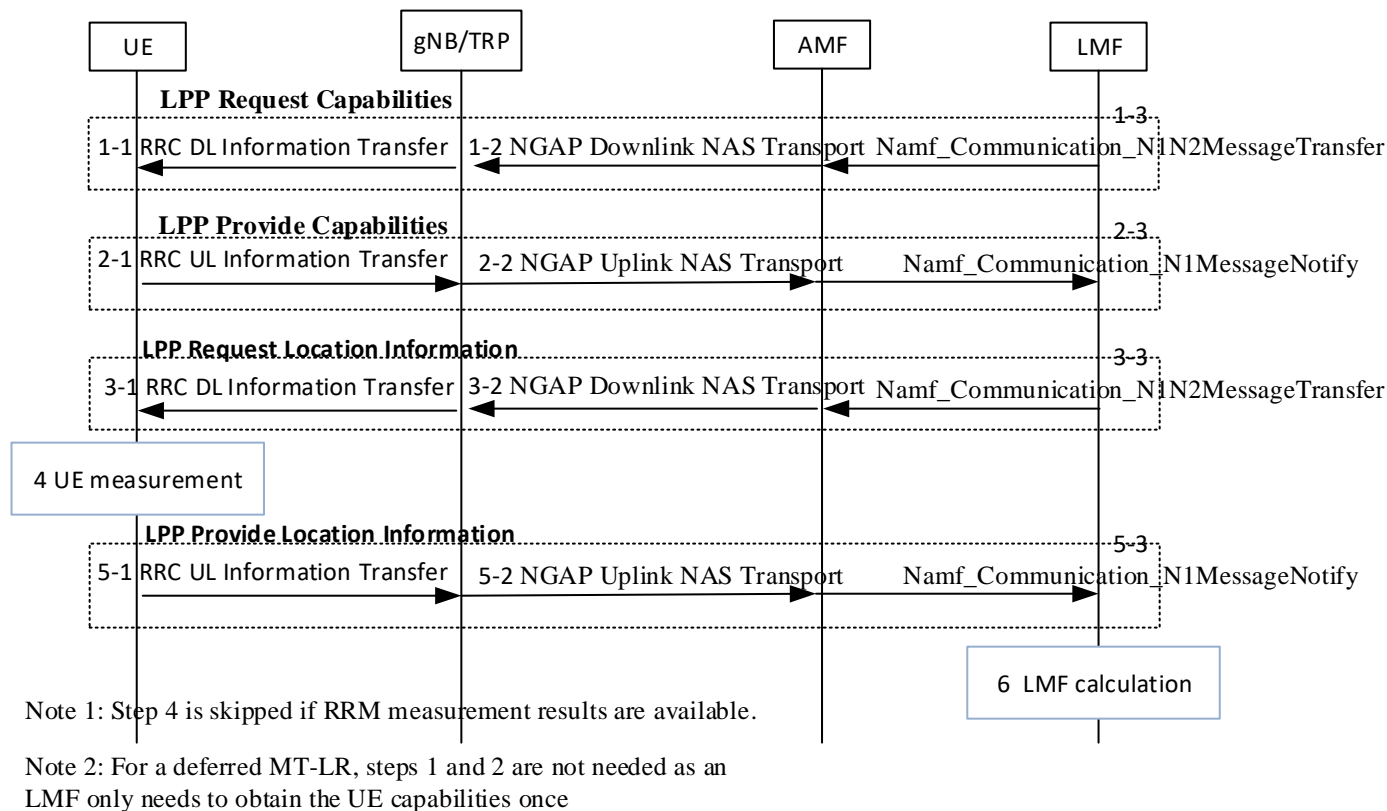


Figure 8.1.3.4-1: Downlink NR E-CID positioning procedure

The latency performance analysis for Downlink NR E-CID are provided in table 8.1.3.3-1.

Table 8.1.3.4-1: Latency performance analysis for Downlink NR E-CID

Step	Delay Value [ms]	Description of Latency Component
Step 1 LPP Request capabilities	18-34.5	Processing delays: 14 ms - UE: $T_{UEProc-RRCDLInfo}$ - gNB: $T_{gNBProc-NAS/LPP}$ - AMF: $T_{AMFProc}$ - LMF: $T_{LMFProc}$ Signalling delay: 4-20.5ms - UE-gNB: T_{UE-gNB} - gNB-AMF: $T_{gNB-AMF}$ - AMF-LMF: $T_{AMF-LMF}$ Note 1: the LPP capability processing delay is counted together in response message.
Step 2 LPP Provide Capabilities	25-54.5	Processing delays: 21-34 ms - UE: - $T_{UEProc-RRCDLInfo}$ - $T_{UEProc-LPPCapab}$ - gNB: $T_{gNBProc-NAS/LPP}$ - AMF: $T_{AMFProc}$ - LMF: $T_{LMFProc}$ Signalling delay: 4-20.5 ms - UE-gNB: T_{UE-gNB} - gNB-AMF: $T_{gNB-AMF}$ - AMF-LMF: $T_{AMF-LMF}$
Step 3 LPP Request Location Information	23-39.5	Processing delays: 19 ms - UE: - $T_{UEProc-RRCDLInfo}$ - $T_{UEProc-LPPLocationRe}$ - gNB: $T_{gNBProc-NAS/LPP}$ - AMF: $T_{AMFProc}$ - LMF: $T_{LMFProc}$ Signalling delay: 4-20.5ms - UE-gNB: T_{UE-gNB} - gNB-AMF: $T_{gNB-AMF}$ - AMF-LMF: $T_{AMF-LMF}$
Step 4 UE measurement		Note 2: not counted;
Step 5 LPP Provide Location Information	20-39.5	Processing delays: 16-19 ms - UE: - $T_{UEProc-RRCDLInfo}$ - $T_{UEProc-LPPLocationRe}$ - gNB: $T_{gNBProc-NAS/LPP}$ - AMF: $T_{AMFProc}$ - LMF: $T_{LMFProc}$ Signalling delay: 4-20.5 ms - UE-gNB: T_{UE-gNB} - gNB-AMF: $T_{gNB-AMF}$ - AMF-LMF: $T_{AMF-LMF}$
Step 6 LMF calculation	2-30	$T_{LMF-Calc}$
Total values	88-198	

Referred to [27], Figure 8.1.3.4-2 shows the messaging between the LMF, the AMF, the gNBs and the UE to perform Uplink NR E-CID procedure.

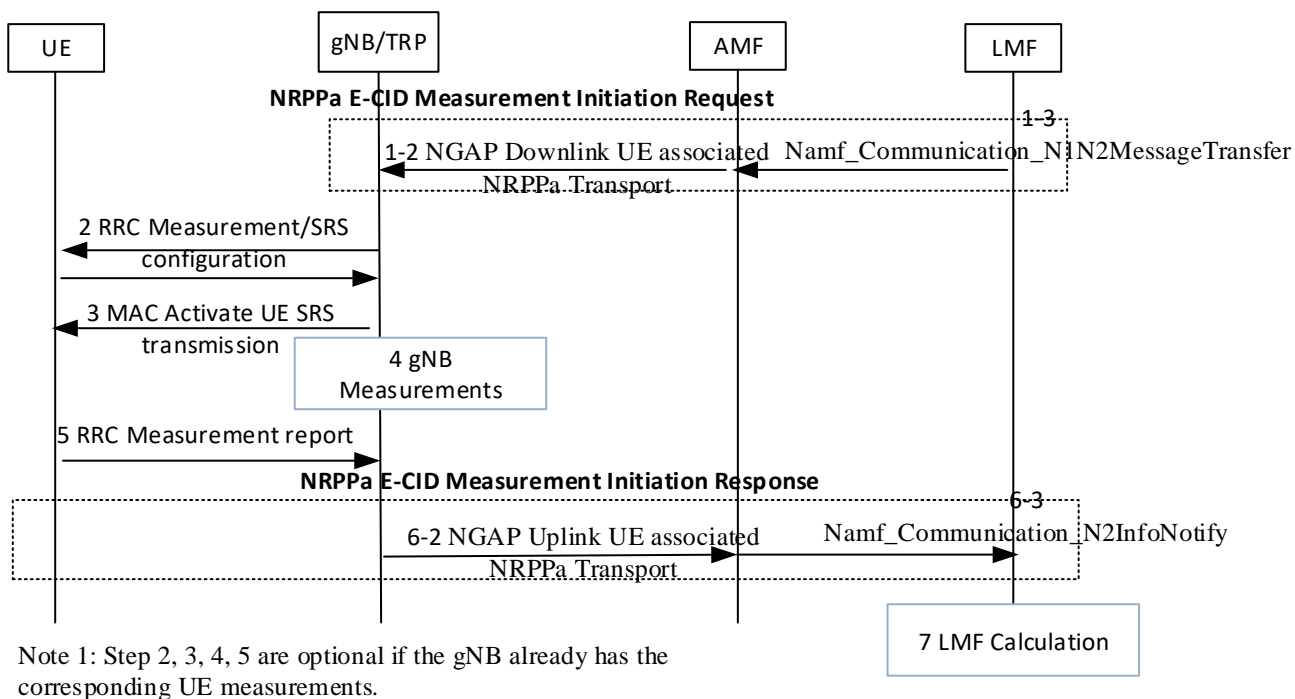


Figure 8.1.3.4-2: Uplink NR E-CID positioning procedure

The latency performance analysis for Uplink NR E-CID are provided in table 8.1.3.3-1.

Table 8.1.3.4-2: Latency performance analysis for Uplink NR E-CID

Step	Delay Value [ms]	Description of Latency Component
Step 1 NRPPa E-CID Measurement Initiation Request	13-29	Processing delays: 9 ms - gNB: $T_{\text{gNBProc-NRPPa}}$ - AMF: T_{AMFProc} - LMF: T_{LMFProc} Signalling delay: 4-20 ms - gNB-AMF: $T_{\text{gNB-AMF}}$ - AMF-LMF: $T_{\text{AMF-LMF}}$
Step 2 RRC Measurement/SRS configuration	13-13.5	Processing delays: 13 ms - UE: $T_{\text{UEProc-RRCReconf}}$ - gNB: $T_{\text{gNBProc-RRC}}$ Signalling delay: 0-0.5ms - UE-gNB: $T_{\text{UE-gNB}}$ Note 1: Should not be counted if the configuration has been configured before the procedure.
Step 3 MAC Activate UE SRS transmission	1-3.5	Processing delays: 1-3ms - UE: $T_{\text{UEProc-MAC-SRSAct}}$ Signalling delay: 0-0.5ms - UE-gNB: $T_{\text{UE-gNB}}$ Note 2: Should not be counted if the periodic or aperiodic SRS is used.
Step 4 UL measurement	12	$T_{\text{UL-Meas}}$
Step 5 RRC Measurement report	5-8.5	Processing delays: 5-8 ms - UE: $T_{\text{UEProc-RRCULInfo}}$ - gNB: $T_{\text{gNBProc-RRC}}$ Signalling delay: 0-0.5ms - UE-gNB: $T_{\text{UE-gNB}}$ Note 3: should not be counted if the gNB already has valid measurement results from the UE.
Step 6 NRPPa E-CID Measurement Initiation Response	13-29	Processing delays: 9 ms - gNB: $T_{\text{gNBProc-NRPPa}}$ - AMF: T_{AMFProc} - LMF: T_{LMFProc} Signalling delay: 4-20 ms - gNB-AMF: $T_{\text{gNB-AMF}}$ - AMF-LMF: $T_{\text{AMF-LMF}}$
Step 7 LMF calculation	2-30	$T_{\text{LMF-Calc}}$
Total values	59-125.5	

8.2 Performance analysis of studied NR positioning enhancements

This clause presents the observations made by sources regarding the studied NR positioning enhancements. Detailed results can be found in annex C.2.

8.2.1 Positioning accuracy analysis for NR positioning enhancements

8.2.1.1 Observations from source [4]

Table 8.2.1.1-1 captures observations based on evaluations results of NR positioning enhancements for horizontal location error.

Table 8.2.1.1-1: NR positioning enhancements – horizontal accuracy performance summary [4]

Simulation case (Horizontal Error)	Gain vs Rel.16 solution, @[90]%, [m]	Accuracy achieved @[90]%	Commercial horizontal accuracy requirements [1]m @[90]% are met - Yes/No. If no, provide performance gaps	IoT horizontal accuracy requirements of [0.2]m @[90]%are met - Yes/No. If no, provide performance gaps	IoT horizontal accuracy requirements of [0.5]m @[90]%are met -Yes/No. If no, provide performance gaps
311, InF-DH422, FR1, UL-TDOA	Rel-16 baseline	9.6631	No	No	No
312, InF-DH422, FR1, UL-TDOA w/ RAIM	9.0062	0.6569	Yes	0.4569	0.1569
313, InF-DH422, FR1, UL-TDOA w/ LOS/NLOS identification	9.452	0.2111	Yes	0.0111	Yes
321, InF-DH422, FR1, UL-TDOA, 100M contiguous	Rel-16 baseline	0.2022	Yes	No	Yes
322, InF-DH422, FR1, UL-TDOA, 200M contiguous	0.1638	0.0384	Yes	Yes	Yes
323, InF-DH422, FR1, UL-TDOA, 50MHz+100MHz (Gap)+50MHz	0.111	0.0912	Yes	Yes	Yes
331, InF-SH, FR1, DL-TDOA, Comb-4 and 4-symbol	Rel-16 baseline	0.0939	Yes	Yes	Yes
332, InF-SH, FR1, DL-TDOA, Comb-4 and 1-symbol	-0.0184	0.1123	Yes	Yes	Yes
333, InF-SH, FR1, DL-TDOA, Comb-12 and 12-symbol	Rel-16 baseline	0.1091	Yes	Yes	Yes
334, InF-SH, FR1, DL-TDOA, Comb-12 and 1-symbol	-0.0108	0.1199	Yes	Yes	Yes
341, InF-SH, FR1, DL-TDOA	Rel-16 baseline	0.0939	Yes	Yes	Yes
342, InF-SH, FR1, DL-TDOA, 20-RB of PRS punctured by SSB	-0.0151	0.109	Yes	Yes	Yes
362, InF-DH422, FR1, UL-TDOA/AoA, ULA 4x1 w/ legacy AoA)	Rel-16 baseline	4.8161	No	No	No
363, InF-DH422, FR1, UL-TDOA/AoA, ULA 4x1 w/ modified AoA	4.6467	0.1694	Yes	Yes	Yes
371, InF-DH422, FR1, Multi-RTT	Rel-16 baseline	0.1694	Yes	Yes	Yes
372, InF-DH422, FR1, E-CID w/ single cell RTT/AoA	-0.0701	0.2395	Yes	No	Yes
381, InF-SH, FR1, UL-TDOA, 100M, 0ns gNB Sync error	Rel-16 baseline	0.1136	Yes	Yes	Yes
382, InF-SH, FR1, UL-TDOA, 100M, 0.2ns gNB Sync error	-0.0316	0.1452	Yes	Yes	Yes
383, InF-SH, FR1, UL-TDOA, 100M, 0.5ns gNB Sync error	-0.1692	0.2828	Yes	No	Yes

384, InF-SH, FR1, UL-TDOA, 100M, 1ns gNB Sync error	-0.2544	0.5372	Yes	No	Barely
385, InF-SH, FR1, UL-TDOA, 200M, 0ns gNB Sync error	FR1 CA baseline	0.025	Yes	Yes	Yes
386, InF-SH, FR1, UL-TDOA, 200M, 0.2ns gNB Sync error	-0.0852	0.1102	Yes	Yes	Yes
387 InF-SH, FR1, UL-TDOA, 200M, 0.5ns gNB Sync error	-0.2409	0.2659	Yes	No	Yes
388 InF-SH, FR1, UL-TDOA, 200M, 1ns gNB Sync error	-0.509	0.534	Yes	No	Barely

8.2.1.2 Observations from source [7]

Table 8.2.1.2-1 captures observations based on evaluations results of NR positioning enhancements for horizontal location error.

Table 8.2.1.2-1: NR positioning enhancements – horizontal accuracy performance summary [7]

Simulation case (Horizontal Error)	Gain vs Rel.16 solution, @[90]%, [m]	Accuracy achieved @[90]%
Case 26	5.140	7.205
Case 27	10.342	2.003
Case 29	2.926	9.248
Case 30	11.946	0.228

8.2.1.3 Observations from source [8]

Table 8.2.1.3-1 captures observations based on evaluations results of NR positioning enhancements for horizontal location error.

Table 8.2.1.3-1: NR positioning enhancements – horizontal accuracy performance summary [8]

Simulation case (Horizontal Error)	Gain vs Rel.16 solution, @[90]%, [m]	Accuracy achieved @[90]%	IIoT horizontal accuracy requirements of [0.2]m @[90]%, are met - Yes/No. If No, provide performance gaps	IIoT horizontal accuracy requirements of [0.5]m @[90]%, are met -Yes/No. If No, provide performance gaps
[Case 1], [InF-HH-2D], [FR1], [DL-TDOA+ DL-CPP]	0.114m Vs CASE 1 in clause 8.1.1.3	0.051	YES	YES
[Case 2], [InF-HH-2D], [FR1], [UL-TDOA+ UL-CPP]	0.1061m Vs CASE 2 in clause 8.1.1.3	0.049	YES	YES

8.2.1.4 Observations from source [13]

Simulation case (Horizontal Error)	Accuracy achieved @[90]%
Case 1, [InF-SH, UL-TDOA, FR1, 100 MHz]	1.94
Case 2, [InF-DH, UL-TDOA, FR1, 100 MHz]	4.2

8.2.1.5 Observations from source [5]

Table 8.2.1.5-1.1 to Table 8.2.1.5-1.9 captures observations based on evaluations results of NR positioning enhancements for horizontal location error.

Table 8.2.1.5-1.1: NR positioning enhancements – horizontal accuracy performance summary for baseline with RAIM [5]

Simulation case (Horizontal Error)	Gain vs Rel.16 solution, @[90]%, [m]	Accuracy achieved @[90]%	IoT horizontal accuracy requirements of [0.2]m @[90]% are met - Yes/No. If no, provide performance gaps
[Case E1], [SH, perfect sync], [FR1], [DL-TDOA, MUSIC, select based on RSRP, RAIM]	3.95	0.099	Yes
[Case E3], [SH, perfect sync], [FR2], [DL-TDOA, MUSIC, select based on RSRP, RAIM]	2.95	0.024	Yes
[Case E5], [DH, perfect sync], [FR1], [DL-TDOA, MUSIC, select based on RSRP, RAIM]	1.49	4.43	4.23
[Case E7], [DH, perfect sync], [FR2], [DL-TDOA, MUSIC, select based on RSRP, RAIM]	1.42	4.35	4.15
[Case E9], [SH, perfect sync], [FR1], [DL-TDOA, MUSIC, select based on first/median peak, RAIM]	0	0.094	Yes
[Case E11], [SH, perfect sync], [FR2], [DL-TDOA, MUSIC, select based on first/median peak, RAIM]	0.007	0.024	Yes
[Case E13], [DH, perfect sync], [FR1], [DL-TDOA, MUSIC, select based on first/median peak, RAIM]	0.43	0.17	Yes
[Case E15], [DH, perfect sync], [FR2], [DL-TDOA, MUSIC, select based on first/median peak, RAIM]	0.015	0.034	Yes
[Case E17], [SH, perfect sync], [FR1], [UL-TDOA, MUSIC, select based on RSRP, RAIM]	4.12	0.10	Yes
[Case E19], [SH, perfect sync], [FR2], [UL-TDOA, MUSIC, select based on RSRP, RAIM]	4.04	0.034	Yes
[Case E21], [DH, perfect sync], [FR1], [UL-TDOA, MUSIC, select based on RSRP, RAIM]	0.37	5.48	5.28
[Case E23], [DH, perfect sync], [FR2], [UL-TDOA, MUSIC, select based on RSRP, RAIM]	1.21	4.55	4.35
[Case E25], [SH, perfect sync], [FR1], [UL-TDOA, MUSIC, select based on first/median peak, RAIM]	0.004	0.083	Yes
[Case E27], [SH, perfect sync], [FR2], [UL-TDOA, MUSIC, select based on first/median peak, RAIM]	0	0.032	Yes
[Case E29], [DH, perfect sync], [FR1], [UL-TDOA, MUSIC, select based on first/median peak, RAIM]	0.41	0.19	Yes
[Case E31], [DH, perfect sync], [FR2], [UL-TDOA, MUSIC, select based on first/median peak, RAIM]	0.008	0.043	Yes
[Case E33], [SH, perfect sync], [FR1], [Multi-RTT, MUSIC, select based on RSRP, RAIM]	4.14	0.11	Yes
[Case E35], [SH, perfect sync], [FR2], [Multi-RTT, MUSIC, select based on RSRP, RAIM]	3.91	0.049	Yes

[Case E37], [DH, perfect sync], [FR1], [Multi-RTT, MUSIC, select based on RSRP, RAIM]	0.99	4.89	4.69
[Case E39], [DH, perfect sync], [FR2], [Multi-RTT, MUSIC, select based on RSRP, RAIM]	1.62	4.12	3.92
[Case E41], [SH, perfect sync], [FR1], [Multi-RTT, MUSIC, select based on first/median peak, RAIM]	0.008	0.092	Yes
[Case E43], [SH, perfect sync], [FR2], [Multi-RTT, MUSIC, select based on first/median peak, RAIM]	0.008	0.030	Yes
[Case E45], [DH, perfect sync], [FR1], [Multi-RTT, MUSIC, select based on first/median peak, RAIM]	0.41	0.19	Yes
[Case E47], [DH, perfect sync], [FR2], [Multi-RTT, MUSIC, select based on first/median peak, RAIM]	0.003	0.048	Yes

Table 8.2.1.5-1.2: NR positioning enhancements – horizontal accuracy performance summary with RAIM and LOS detection [5]

Simulation case (Horizontal Error)	Gain vs Rel.16 solution, @[90]%, [m]	Accuracy achieved @[90]%	IoT horizontal accuracy requirements of [0.2]m @[90]%are met - Yes/No. If no, provide performance gaps
[Case E49], [SH, perfect sync], [FR1], [DL-TDOA, RAIM]		0.094	Yes
[Case E50], [SH, perfect sync], [FR1], [100% LOS detection probability without RAIM]		0.096	Yes
[Case E51], [SH, perfect sync], [FR1], [DL-TDOA, known LOS+ RAIM]		0.083	Yes
[Case E52], [SH, perfect sync], [FR1], [DL-TDOA, 95% LOS detection probability without RAIM]		2.86	2.66
[Case E53], [SH, perfect sync], [FR1], [DL-TDOA, 90% LOS detection probability without RAIM]		4.54	4.34
[Case E54], [SH, perfect sync], [FR1], [DL-TDOA, baseline no LOS detection without RAIM]		4.62	4.42
[Case E55], [DH, perfect sync], [FR1], [DL-TDOA, RAIM]		0.17	Yes
[Case E56], [DH, perfect sync], [FR1], [DL-TDOA, 100% LOS detection probability without RAIM]		0.33	0.13
[Case E57], [DH, perfect sync], [FR1], [DL-TDOA, known LOS+ RAIM]		0.17	Yes
[Case E58], [DH, perfect sync], [FR1], [DL-TDOA, 95% LOS detection probability without RAIM]		3.40	3.20
[Case E59], [DH, perfect sync], [FR1], [DL-TDOA, 90% LOS detection probability without RAIM]		3.43	3.23
[Case E60], [DH, perfect sync], [FR1], [DL-TDOA, baseline no LOS detection without RAIM]		8.64	8.44

Table 8.2.1.5-1.3: NR positioning enhancements – horizontal accuracy performance summary with different timing measurement reporting granularity [5]

Simulation case (Horizontal Error)	Gain vs Rel.16 solution, @[90]%, [m]	Accuracy achieved @[90]%	IoT horizontal accuracy requirements of [0.2]m @[90]%are met - Yes/No. If no, provide performance gaps
[Case E61], [SH, perfect sync], [FR1], [DL-TDOA] [granularity 0.5ns]		0.16	Yes
[Case E62], [SH, perfect sync], [FR1], [DL-TDOA] [granularity 1ns]		0.21	0.1
[Case E63], [SH, perfect sync], [FR1], [DL-TDOA] [granularity 2ns]		0.47	0.27
[Case E64], [DH, perfect sync], [FR1], [DL-TDOA] [granularity 0.5ns]		0.17	Yes
[Case E65], [DH, perfect sync], [FR1], [DL-TDOA] [granularity 1ns]		0.35	0.15
[Case E66], [DH, perfect sync], [FR1], [DL-TDOA] [granularity 2ns]		0.59	0.39

Table 8.2.1.5-1.4: NR positioning enhancements – horizontal accuracy performance summary with different Rx/Tx timing error [5]

Simulation case (Horizontal Error)	Gain vs Rel.16 solution, @[90]%, [m]	Accuracy achieved @[90]%	IIoT horizontal accuracy requirements of [0.2]m @[90]% are met - Yes/No. If no, provide performance gaps
[Case E67], [SH, perfect sync], [FR1], [DL-TDOA] [BS timing error 0.5ns, UE timing error 0.5ns]		0.30	0.10
[Case E68], [SH, perfect sync], [FR1], [DL-TDOA] [BS timing error 0.5ns, UE timing error 1ns]		0.34	0.14
[Case E69], [SH, perfect sync], [FR1], [DL-TDOA] [BS timing error 0.5ns, UE timing error 2ns]		0.36	0.16
[Case E70], [SH, perfect sync], [FR1], [DL-TDOA] [BS timing error 0.5ns, UE timing error 3ns]		0.35	0.15
[Case E71], [SH, perfect sync], [FR1], [DL-TDOA] [BS timing error 0.5ns, UE timing error 5ns]		0.37	0.17
[Case E72], [SH, perfect sync], [FR1], [DL-TDOA] [BS timing error 1ns, UE timing error 0.5ns]		0.42	0.22
[Case E73], [SH, perfect sync], [FR1], [DL-TDOA] [BS timing error 2ns, UE timing error 0.5ns]		0.83	0.63
[Case E74], [SH, perfect sync], [FR1], [DL-TDOA] [BS timing error 3ns, UE timing error 0.5ns]		1.07	0.87
[Case E75], [SH, perfect sync], [FR1], [DL-TDOA] [BS timing error 5ns, UE timing error 0.5ns]		1.87	1.67
[Case E76], [DH, perfect sync], [FR1], [DL-TDOA] [BS timing error 0.5ns, UE timing error 0.5ns]		0.31	0.11
[Case E77], [DH, perfect sync], [FR1], [DL-TDOA] [BS timing error 0.5ns, UE timing error 1ns]		0.32	0.12
[Case E78], [DH, perfect sync], [FR1], [DL-TDOA] [BS timing error 0.5ns, UE timing error 2ns]		0.32	0.12
[Case E79], [DH, perfect sync], [FR1], [DL-TDOA] [BS timing error 0.5ns, UE timing error 3ns]		0.28	0.08
[Case E80], [DH, perfect sync], [FR1], [DL-TDOA] [BS timing error 0.5ns, UE timing error 5ns]		0.31	0.11
[Case E81], [DH, perfect sync], [FR1], [DL-TDOA] [BS timing error 1ns, UE timing error 0.5ns]		0.40	0.20

[Case E82] [DH, perfect sync], [FR1], [DL-TDOA] [BS timing error 2ns, UE timing error 0.5ns]		0.76	0.56
[[Case E83], [DH, perfect sync], [FR1], [DL-TDOA] [BS timing error 3ns, UE timing error 0.5ns]		0.88	0.68
[Case E84], [DH, perfect sync], [FR1], [DL-TDOA] [BS timing error 5ns, UE timing error 0.5ns]		1.94	1.74
[Case E85], [SH, perfect sync], [FR1], [Multi-RTT] [BS timing error 0.5ns, UE timing error 0.5ns]		0.24	0.04
[Case E86], [SH, perfect sync], [FR1], [Multi-RTT] [BS timing error 0.5ns, UE timing error 1ns]		0.23	0.03
[Case E87], [SH, perfect sync], [FR1], [Multi-RTT] [BS timing error 0.5ns, UE timing error 2ns]		0.27	0.07
[Case E88], [SH, perfect sync], [FR1], [Multi-RTT] [BS timing error 0.5ns, UE timing error 3ns]		0.33	0.13
[Case E89], [SH, perfect sync], [FR1], [Multi-RTT] [BS timing error 0.5ns, UE timing error 5ns]		0.44	0.24
[Case E90], [SH, perfect sync], [FR1], [Multi-RTT] [BS timing error 1ns, UE timing error 0.5ns]		0.28	0.08
[Case E91], [SH, perfect sync], [FR1], [Multi-RTT] [BS timing error 2ns, UE timing error 0.5ns]		0.34	0.14
[[Case E92], [SH, perfect sync], [FR1], [Multi-RTT] [BS timing error 3ns, UE timing error 0.5ns]		0.76	0.56
[Case E93], [SH, perfect sync], [FR1], [Multi-RTT] [BS timing error 5ns, UE timing error 0.5ns]		1.26	1.06
[Case E94], [DH, perfect sync], [FR1], [Multi-RTT] [BS timing error 0.5ns, UE timing error 0.5ns]		0.24	0.04
[Case E95], [DH, perfect sync], [FR1], [Multi-RTT] [BS timing error 0.5ns, UE timing error 1ns]		0.24	0.04
[Case E96], [DH, perfect sync], [FR1], [Multi-RTT] [BS timing error 0.5ns, UE timing error 2ns]		0.28	0.08
[Case E97], [DH, perfect sync], [FR1], [Multi-RTT] [BS timing error 0.5ns, UE timing error 3ns]		0.36	0.16

[Case E98], [DH, perfect sync], [FR1], [Multi-RTT] [BS timing error 0.5ns, UE timing error 5ns]		0.46	0.26
[Case E99], [DH, perfect sync], [FR1], [Multi-RTT] [BS timing error 1ns, UE timing error 0.5ns]		0.34	0.14
[Case E100], [DH, perfect sync], [FR1], [Multi-RTT] [BS timing error 2ns, UE timing error 0.5ns]		0.48	0.28
[[Case E101], [DH, perfect sync], [FR1], [Multi-RTT] [BS timing error 3ns, UE timing error 0.5ns]		0.87	0.67
[Case E102], [DH, perfect sync], [FR1], [Multi-RTT] [BS timing error 5ns, UE timing error 0.5ns]		1.28	1.08

Table 8.2.1.5-1.5: NR positioning enhancements – horizontal accuracy performance summary with aggregation of DL positioning frequency layers [5]

Simulation case (Horizontal Error)	Gain vs Rel.16 solution, @[90]%, [m]	Accuracy achieved @[90]%	IoT horizontal accuracy requirements of [0.2]m @[90]%are met - Yes/No. If no, provide performance gaps
[Case E103], [SH, perfect sync], [FR1], [50M]		0.31	0.11
[Case E104], [SH, perfect sync], [FR1], [100M]		0.094	Yes
[Case E105], [SH, perfect sync], [FR1], [50M+50M]		0.21	0.01
[Case E106], [DH, perfect sync], [FR1], [50M]		0.44	0.24
[Case E107], [DH, perfect sync], [FR1], [100M]		0.17	Yes
Case E108], [DH, perfect sync], [FR1], [50M+50M]		0.23	0.03

Table 8.2.1.5-1.6: NR positioning enhancements – horizontal accuracy performance summary with aggregation of DL positioning frequency layers with timing offset [22]

Simulation case (Horizontal Error)	Gain vs Rel.16 solution, @[90]%, [m]	Accuracy achieved @[90]%	IoT horizontal accuracy requirements of [0.2]m @[90]%are met - Yes/No. If no, provide performance gaps
[Case E121], [SH, perfect sync], [FR1], [50M+50M] [timing offset 1ns]		0.46	0.26
[Case E122], [SH, perfect sync], [FR1], [50M+50M] [timing offset 5ns]		2.03	1.83
[Case E123], [SH, perfect sync], [FR1], [50M+50M] [timing offset 10ns]		5.46	5.26
[Case E124], [SH, perfect sync], [FR1], [50M+50M] [timing offset 20ns]		10.05	9.85
[Case E125], [DH, perfect sync], [FR1], [50M+50M] [timing offset 1ns]		0.96	0.76
[Case E126], [DH, perfect sync], [FR1], [50M+50M] [timing offset 5ns]		3.90	3.70
[Case E127], [DH, perfect sync], [FR1], [50M+50M] [timing offset 10ns]		8.34	8.14
[Case E128], [DH, perfect sync], [FR1], [50M+50M] [timing offset 20ns]		10.69	10.49

Table 8.2.1.5-1.7: NR positioning enhancements – horizontal accuracy performance with reduced Rx/Tx timing error and synchronization error [22]

Simulation case (Horizontal Error)	Gain vs Rel.16 solution, @[90]%, [m]	Accuracy achieved @[90]%	IoT horizontal accuracy requirements of [0.2]m @[90]%are met - Yes/No. If no, provide performance gaps
[Case E115], [SH, sync error 50ns], [FR1], [DL-TDOA] [sync error reduced by differential positioning]		0.11	Yes
[Case E116], [SH, perfect sync], [FR1], [DL-TDOA] [BS timing error 5ns, UE timing error 0.5ns] [Rx/Tx timing error reduced by differential positioning]		0.13	Yes
[Case E117], [SH, sync error 50ns], [FR1], [UL-TDOA] [sync error reduced by UL- TDOA+AOA]		3.16	2.96
[Case E118], [SH, perfect sync], [FR1], [UL-TDOA] [BS timing error 5ns, UE timing error 0.5ns] [Rx/Tx timing error reduced by UL-TDOA+AOA]		1.50	1.30
[Case E119], [DH, (60%,6,2), perfect sync], [FR1], [machine learning]		4.60	4.40
[Case E120], [DH, (60%,6,2), sync error 50ns], [FR1], [machine learning]		5.12	4.92

Table 8.2.1.5-1.8: NR positioning enhancements – horizontal accuracy performance summary for IOO scenario without absolute time of arrival modelling [23]

Simulation case (Horizontal Error)	Gain vs Rel.1 6 soluti on, @[90]%, [m]	Accuracy achieved @[90]%	Commercial horizontal accuracy requirements [1]m @[90]% are met - Yes/No. If no, provide performance gaps
[Case E109], [IOO scenario without absolute time of arrival modelling, perfect sync], [FR1], [DL-TDOA, MUSIC, select based on first/median peak] (Case 63 in [5])		0.80	Yes
[Case E110], [IOO scenario without absolute time of arrival modelling, perfect sync], [FR2], [DL-TDOA, MUSIC, select based on first/median peak] (Case 64 in [5])		0.54	Yes
[Case E111], [IOO scenario without absolute time of arrival modelling, perfect sync], [FR1], [UL-TDOA, MUSIC, select based on first/median peak] (Case 65 in [5])		0.84	Yes
[Case E112], [IOO scenario without absolute time of arrival modelling, perfect sync], [FR2], [UL-TDOA, MUSIC, select based on first/median peak] (Case 66 in [5])		0.56	Yes
[Case E113], [IOO scenario without absolute time of arrival modelling, perfect sync], [FR1], [Multi-RTT, MUSIC, select based on first/median peak] (Case 67 in [5])		0.68	Yes
[Case E114], [IOO scenario without absolute time of arrival modelling, perfect sync], [FR2], [Multi-RTT MUSIC, select based on first/median peak] (Case 68 in [5])		0.50	Yes

Table 8.2.1.5-1.9: NR positioning enhancements – horizontal accuracy performance summary for IOO scenario with absolute time of arrival modelling [23]

Simulation case (Horizontal Error)	Gain vs Rel.1 6 solution, @[90]%, [m]	Accuracy achieved @[90]%	Commercial horizontal accuracy requirements [1]m @[90]% are met - Yes/No. If no, provide performance gaps
[Case E129], [IOO scenario with absolute time of arrival modelling, perfect sync], [FR1], [DL-TDOA, MUSIC, select based on first/median peak]		0.82	Yes
[Case E130], [IOO scenario with absolute time of arrival modelling, perfect sync], [FR2], [DL-TDOA, MUSIC, select based on first/median peak]		0.56	Yes
[Case E131], [IOO scenario with absolute time of arrival modelling, perfect sync], [FR1], [UL-TDOA, MUSIC, select based on first/median peak]		0.86	Yes
[Case E132], [IOO scenario with absolute time of arrival modelling, perfect sync], [FR2], [UL-TDOA, MUSIC, select based on first/median peak]		0.62	Yes
[Case E133], [IOO scenario with absolute time of arrival modelling, perfect sync], [FR1], [Multi-RTT, MUSIC, select based on first/median peak]		0.68	Yes
[Case E134], [IOO scenario with absolute time of arrival modelling, perfect sync], [FR2], [Multi-RTT MUSIC, select based on first/median peak]		0.54	Yes

Table 8.2.1.5-2 captures observations based on evaluations results of NR positioning enhancements for vertical location error.

Table 8.2.1.5-2: NR positioning enhancements – vertical accuracy performance summary [23]

Simulation case (Vertical Error)	Gain vs Rel16 solution @[90]%, [m]	Accuracy achieved @[90]%	IoT horizontal accuracy requirements of [1]m @[90]% are met - Yes/No. If no, provide performance gaps @[90]%
[Case E-V1], [SH, perfect sync], [FR1], [BS height = 8m UE height =1.5m] [DL-TDOA, MUSIC, select based on first/median peak]		0.58	Yes
[Case E-V2], [DH, perfect sync], [FR1], [BS height = 8m UE height =1.5m] [DL-TDOA, MUSIC, select based on first/median peak]		0.64	Yes
[Case E-V3], [SH, perfect sync], [FR1], [BS height = {4,8}m UE height =1.5m] [DL-TDOA, MUSIC, select based on first/median peak]		1.25	0.25
[Case E-V4], [DH, perfect sync], [FR1], [BS height = {4,8}m UE height =1.5m] [DL-TDOA, MUSIC, select based on first/median peak]		4.62	3.62
[Case E-V5], [SH, perfect sync], [FR1], [BS height = 8m UE height =[0.5,2]m] [DL-TDOA, MUSIC, select based on first/median peak]		0.66	Yes
[Case E-V6], [DH, perfect sync], [FR1], [BS height = 8m UE height =[0.5,2]m] [DL-TDOA, MUSIC, select based on first/median peak]		3.16	2.16
[Case E-V7], [SH, perfect sync], [FR1], [BS height = {4,8}m UE height =[0.5,2]m] [DL-TDOA, MUSIC, select based on first/median peak]		1.27	0.27
[Case E-V8], [DH, perfect sync], [FR1], [BS height = {4,8}m UE height =[0.5,2]m] [DL-TDOA, MUSIC, select based on first/median peak]		4.93	3.93

8.2.1.6 Observations from source [12]

Table 8.2.1.6-1 captures observations based on evaluations results of NR positioning enhancements for horizontal location error.

Table 8.2.1.6-1: NR positioning enhancements – horizontal accuracy performance summary [12]

Simulation cases (Horizontal Error)	Gain vs Rel.16 solution, @[90]%, [m]	Accuracy achieved @[90]%	IoT horizontal accuracy requirements of [0.2]m @[90]%are met - Yes/No. If No, provide performance gaps	IoT horizontal accuracy requirements of [0.5]m @[90]%are met -Yes/No. If No, provide performance gaps
Case1, (InF-SH, NLOS classification FR1)	7.7	0.87	No, 0.67	No, 0.3
Case2, (InF-SH, NLOS mitigation FR1)	5.46	3.12	No, 2.9	No, 2.62
Case3, (InF-SH, NLOS classification + NLOS mitigation FR1)	8.27	0.31	No, 0.11	Yes
Case4, (InF-DH, NLOS classification FR1)	2.4	12.5	No, 12.3	No, 12
Case5, (InF-DH, NLOS mitigation FR1)	9.4	5.49	No, 5.29	No, 4.66
Case6, (InF-DH, NLOS classification FR1)	12.43	2.47	No, 2.27	No, 1.97
Case7, (InF-SH, Ideal NLOS classification FR1)	8.27	0.23	No, 0.03	Yes,
Case8, (InF-DH, Ideal NLOS classification FR1)	14.59	0.31	No, 0.11	Yes

8.2.1.7 Observations from source [10]

Table 8.2.1.7-1 captures observations based on evaluations results of NR positioning enhancements for horizontal location error.

Table 8.2.1.7-1: NR positioning enhancements – horizontal accuracy performance summary [10]

Simulation case (Horizontal Error)	Gain vs Rel.16 solution, @[90]%, [m]	Accuracy achieved @[90]%
Case 13, InF-SH, FR1, DL-TDOA	0.48	0.37
Case 14, InF-DH, FR1, DL-TDOA	4.26	1.94
Case 15, InF-SH, FR2, DL-TDOA	0.44	0.21
Case 16, InF-DH, FR2, DL-TDOA	16.41	0.89
Case 17, InF-SH, FR1, UL-TDOA	0.37	0.4
Case 18, InF-DH, FR1, UL-TDOA	1.73	4.4
Case 19, InF-SH, FR2, UL-TDOA	0.66	0.24
Case 20, InF-DH, FR2, UL-TDOA	16.22	0.68
Case 21, InF-SH, FR1, Multi-RTT	0.08	0.17
Case 22, InF-DH, FR1, Multi-RTT	16.00	0.3
Case 23, InF-SH, FR2, Multi-RTT	0.80	0.1
Case 24, InF-DH, FR2, Multi-RTT	7.55	0.17
Case 25, InF-SH, FR1, Multi-RTT + vertical AoA	0.15	0.1
Case 26, InF-DH, FR1, Multi-RTT + vertical AoA	16.11	0.19
Case 27, InF-SH, FR2, Multi-RTT + vertical AoA	0.82	0.08
Case 28, InF-DH, FR2, Multi-RTT + vertical AoA	7.52	0.2
Case 33, InF-SH, FR1, Multi-RTT	0.19	0.06
Case 34, InF-DH, FR1, Multi-RTT	16.19	0.11
Case 35, InF-SH, FR2, Multi-RTT	0.85	0.05
Case 36, InF-DH, FR2, Multi-RTT	7.65	0.07

Table 8.2.1.7-2 captures observations based on evaluations results of NR positioning enhancements for vertical location error.

Table 8.2.1.7-2: NR positioning enhancements – vertical accuracy performance summary [10]

Simulation case (Horizontal Error)	Gain vs Rel.16 solution, @[90]%, [m]	Accuracy achieved @[90]%
Case 13, InF-SH, FR1, DL-TDOA	1.60	6.9
Case 14, InF-DH, FR1, DL-TDOA	0.2	12.4
Case 15, InF-SH, FR2, DL-TDOA	6.28	6.6
Case 16, InF-DH, FR2, DL-TDOA	57.60	5.8
Case 17, InF-SH, FR1, UL-TDOA	0.1	12.8
Case 18, InF-DH, FR1, UL-TDOA	0.	12.9
Case 19, InF-SH, FR2, UL-TDOA	1.70	11.3
Case 20, InF-DH, FR2, UL-TDOA	62.14	0.64
Case 21, InF-SH, FR1, Multi-RTT	12.21	0.89
Case 22, InF-DH, FR1, Multi-RTT	65.51	0.49
Case 23, InF-SH, FR2, Multi-RTT	5.45	1
Case 24, InF-DH, FR2, Multi-RTT	6.62	0.45
Case 25, InF-SH, FR1, Multi-RTT + vertical AoA	12.83	0.27
Case 26, InF-DH, FR1, Multi-RTT + vertical AoA	65.80	0.2
Case 27, InF-SH, FR2, Multi-RTT + vertical AoA	6.37	0.08
Case 28, InF-DH, FR2, Multi-RTT + vertical AoA	7.01	0.06
Case 33, InF-SH, FR1, Multi-RTT	12.70	0.4
Case 34, InF-DH, FR1, Multi-RTT	65.81	0.19
Case 35, InF-SH, FR2, Multi-RTT	6.06	0.39
Case 36, InF-DH, FR2, Multi-RTT	6.82	0.25

8.2.1.8 Observations from source [18]

Table 8.2.1.8-1 captures observations based on evaluations results of NR positioning enhancements for horizontal location error.

Table 8.2.1.8-1: NR positioning enhancements – horizontal accuracy performance summary [18]

Simulation case (Horizontal Error)	Gain vs Rel.16 solution, @[90] %, [m]	Commercial horizontal accuracy requirements [1]m @[90]% are met - Yes/No. If no, provide performance gaps	IIoT horizontal accuracy requirements of [0.2]m @[90]%are met - Yes/No. If no, provide performance gaps	IIoT horizontal accuracy requirements of [0.5]m @[90]%are met -Yes/No. If no, provide performance gaps
Case 4- config 220 (InF-DH, FR1,UL- TDOA)	N.A.	Yes	No (0.70)	No (0.70)
Case 5- config 320 (InF-DH, FR1,UL- TDOA)	N.A.	Yes	No (0.45)	Yes (0.45)
Case 6- config 420 (InF-DH, FR1,UL- TDOA)	N.A.	Yes	No (0.43)	Yes
Case 7- config 421 (InF-DH, FR1,UL- TDOA)	N.A.	No(>3.00)	No(>3)	No(>3)
Case 8- config 422 (InF-DH, FR1,UL- TDOA)	N.A.	Yes	No(0.44)	Yes
Case 9- config 423 (InF-DH, FR1,UL- TDOA)	N.A.	Yes	No (0.59)	No (0.59)
Case 10- config 443 (InF-DH, FR1,UL- TDOA)	N.A.	Yes	No (0.50)	Yes
Case 11- config 444 (InF-DH, FR1,UL- TDOA)	N.A.	Yes	No (0.49)	Yes
Case 12- config 447 (InF-DH, FR1,UL- TDOA)	N.A.	Yes	No(0.95)	Yes
Case 13- config 552 (InF-DH, FR1,UL- TDOA)	N.A.	No(1.70)	No(1.70)	Yes
Case 14- config 554 (InF-DH, FR1,UL- TDOA)	N.A.	Yes	Yes	Yes

Table 8.2.1.8-2 captures observations based on evaluations results of NR positioning enhancements for vertical location error.

Table 8.2.1.8-2: NR positioning enhancements – vertical accuracy performance summary [18]

Simulation case (Vertical Error)	Gain vs Rel16 solution @[90]%, [m]	Commercial vertical accuracy requirements [3]m @[90]% are met - Yes/No. If no, provide performance gaps @[90]%	IoT vertical accuracy requirements of [0.2]m @[90]% are met - Yes/No. If no, provide performance gaps @[90]%	IoT vertical accuracy requirements of [1]m at @[90]% are met - Yes/No. If no, provide performance gaps @[90]%
Case 4- config 220 (InF-DH, FR1,UL- TDOA)	N.A.	Yes	No(1.84)	No(1.84)
Case 5- config 320 (InF-DH, FR1,UL- TDOA)	N.A.	Yes	No(1.19)	No(1.19)
Case 6- config 420 (InF-DH, FR1,UL- TDOA)	N.A.	Yes	No(1.12)	No(1.12)
Case 7- config 421 (InF-DH, FR1,UL- TDOA)	N.A.	No(>3)	No(>3)	No(>3)
Case 8- config 422 (InF-DH, FR1,UL- TDOA)	N.A.	Yes	No(1.15)	No(1.15)
Case 9- config 423 (InF-DH, FR1,UL- TDOA)	N.A.	Yes	No(1.56)	No(1.56)
Case 10- config 443 (InF-DH, FR1,UL- TDOA)	N.A.	Yes	No(1.12)	No(1.12)
Case 11- config 444 (InF-DH, FR1,UL- TDOA)	N.A.	Yes	No(1.43)	No(1.43)
Case 12- config 447 (InF-DH, FR1,UL- TDOA)	N.A.	Yes	No(2.23)	No(2.23)
Case 13- config 552 (InF-DH, FR1,UL- TDOA)	N.A.	No(>3)	No(>3)	No(>3)
Case 14- config 554 (InF-DH, FR1,UL- TDOA)	N.A.	Yes	No (0.24)	Yes

8.2.1.9 Observations from source [14]

Table 8.2.1.9-1 captures observations based on evaluations results of NR positioning enhancements for horizontal location error.

Table 8.2.1.9-1: NR positioning enhancements – horizontal accuracy performance summary [14]

Simulation case (Horizontal Error)	Accuracy achieved @[90]%
[Case 7], [InF-SH], [FR2], [400 MHz], [Comb-6], [6dB PB]	0.074
[Case 8], [InF-SH], [FR1], [100 MHz], [Comb-6], [6dB PB]	0.38
[Case 9], [InF-DH], [FR2], [400 MHz], [Comb-6], [6dB PB]	1.96
[Case 10], [InF-DH], [FR1], [100 MHz], [Comb-6], [6dB PB]	2.13
[Case 11], [InH-OO], [FR2], [400 MHz], [Comb-6], [6dB PB]	0.31
[Case 12], [InH-OO], [FR1], [100 MHz], [Comb-6], [6dB PB]	0.69
[Case 21], [InF-SH], [FR2], [400 MHz], [Comb-4], [6dB PB]	0.086
[Case 22], [InF-SH], [FR2], [100 MHz], [Comb-4], [6dB PB]	0.36
[Case 23], [InF-SH], [FR2], [50 MHz], [Comb-4], [6dB PB]	0.77
[Case 24], [InF-SH], [FR2], [20 MHz], [Comb-4], [6dB PB]	1.45

Table 8.2.1.9-2 captures observations based on evaluations results of NR positioning enhancements for vertical location error.

Table 8.2.1.9-2: NR positioning enhancements – vertical accuracy performance summary [14]

Simulation case (Vertical Error)	Accuracy achieved @[90]%
[Case 13], [InF-SH], [FR2], [400 MHz], [Comb-6], [6dB PB], [UEH ∈ [0.5, 2] m]	0.77
[Case 14], [InF-SH], [FR1], [100 MHz], [Comb-6], [6dB PB], [UEH ∈ [0.5, 2] m]	1.51
[Case 15], [InF-DH], [FR2], [400 MHz], [Comb-6], [6dB PB], [UEH ∈ [0.5, 2] m]	1.34
[Case 16], [InF-DH], [FR1], [100 MHz], [Comb-6], [6dB PB], [UEH ∈ [0.5, 2] m]	1.47
[Case 17], [InF-SH], [FR2], [400 MHz], [Comb-6], [6dB PB], [UEH ∈ [0, 8] m]	1.34
[Case 18], [InF-SH], [FR1], [100 MHz], [Comb-6], [6dB PB], [UEH ∈ [0, 8] m]	1.73
[Case 19], [InF-DH], [FR2], [400 MHz], [Comb-6], [6dB PB], [UEH ∈ [0, 8] m]	2.11
[Case 20], [InF-DH], [FR1], [100 MHz], [Comb-6], [6dB PB], [UEH ∈ [0, 8] m]	2.57

8.2.1.10 Observations from source [21]

Table 8.2.1.10-1 captures observations based on evaluations results of NR positioning enhancements for horizontal location error.

Table 8.2.1.10-1: NR positioning enhancements – horizontal accuracy performance summary [21]

Simulation case (Horizontal Error)	Gain vs Rel.16 solution, @[90]%, [m]	Accuracy achieved @[90]%
[20] E2, Inf DH, FR1, DL TDOA LOS detection	9.6m	8.4m
[20] E20, Inf SH FR2, UL TDOA multipanel	-0.002	0.034039
[21] E21 Inf SH FR2, UL TDOA multipanel	3.81821	0.02989
[21] E22 Inf SH FR2, DL TDOA multipanel	-0.003	0.037037
[21] E23 Inf SH FR2, DL TDOA multipanel	3.7881	0.03662
[21] E30, Inf SH, FR1, DL TDOA 1-symbol PRS	-0.06	0.54665
[21] E33, IOO, FR1, DL TDOA 1-symbol PRS	0.02	1.404678
[21] E36, Inf SH, FR1, DL TDOA 1-symbol PRS	0.09	0.719702
[21] E39, IOO, FR1, DL TDOA 1-symbol PRS	0.08	1.512598
[21] E42, Inf SH, FR1, DL TDOA 1-symbol PRS	0.3	0.912933
[21] E45, IOO, FR1, DL TDOA 1-symbol PRS	0.31	1.732023
[21] E48, Inf DH, FR1, DL TDOA thresholding	-0.05	15.788375
[21] E49, Inf DH, FR1, DL TDOA thresholding	0,29	16.022874
[21] E50, Inf DH, FR1, DL TDOA thresholding	-1.25	16.984019
[21] E51, Inf DH, FR1, DL TDOA thresholding	-1.68	17.412632
[21] E52, Inf DH, FR1, DL TDOA thresholding	-4.05	19.787138
[21] E53, Inf DH, FR1, DL TDOA thresholding	-6.88	22.610367
[21] E54, Inf SH, FR1, DL TDOA SRS CS unfolding (PAPR preservation)	13.4	2.52
[21] E55, IOO, FR1, DL TDOA SRS CS unfolding (corr optimization)	12.98	3.04
[21] E58, Inf DH, FR1, DL TDOA PRS aggregation	1.09	13.91966
[21] E59, Inf DH, FR1, DL TDOA PRS aggregation	-0.005	15.01508
[21] E61, Inf SH, FR1, DL TDOA PRS aggregation	0.1798	0.079559
[21] E62, Inf SH, FR1, DL TDOA PRS aggregation	-0.016	0.275798
[21] E63, Inf SH, FR1, DL TDOA PRS aggregation	-1.18	1.447441

8.2.1.11 Observations from source [17]

Table 8.2.1.11-1 captures observations based on evaluations results of NR positioning enhancements for horizontal location error.

Table 8.2.1.11-1: NR positioning enhancements – horizontal accuracy performance summary [17]

Simulation case (Horizontal Error)	Commercial horizontal accuracy requirements [1]m @[90]% are met - Yes/No. If no, provide performance gaps @[90]%
Case 22, InH, FR1, Phase offset = 0 degrees, Frequency-domain Stitching	0.5
Case 22, InH, FR1, Phase offset = 2 degrees, Frequency-domain Stitching	0.5
Case 22, InH, FR1, Phase offset = 4 degrees, Frequency-domain Stitching	0.5
Case 22, InH, FR1, Phase offset = 8 degrees, Frequency-domain Stitching	1.5
Case 22, InH, FR1, Phase offset = 10 degrees, Frequency-domain Stitching	1.5
Case 23, InH, FR1, Phase offset = 0 degrees, Frequency-domain Stitching	Yes
Case 23, InH, FR1, Phase offset = 4 degrees, Frequency-domain Stitching	1
Case 23, InH, FR1, Phase offset = 8 degrees, Frequency-domain Stitching	1.4
Case 23, InH, FR1, Phase offset = 10 degrees, Frequency-domain Stitching	1.5
Case 24, InH, FR1, Channel Spacing = 0 MHz, Frequency-domain Stitching	2
Case 24, InH, FR1, Channel Spacing = 7.2 MHz, Frequency-domain Stitching	3
Case 24, InH, FR1, Channel Spacing = 14.4 MHz, Frequency-domain Stitching	4
Case 24, InH, FR1, Channel Spacing = 36 MHz, Frequency-domain Stitching	4.5
Case 25, UMI, FR1, Phase offset = 0 degrees, Frequency-domain Stitching	Yes
Case 25, UMI, FR1, Phase offset = 4 degrees, Frequency-domain Stitching	0.2
Case 25, UMI, FR1, Phase offset = 8 degrees, Frequency-domain Stitching	0.5
Case 25, UMI, FR1, Phase offset = 12 degrees, Frequency-domain Stitching	1.2
Case 25, UMI, FR1, Phase offset = 18 degrees, Frequency-domain Stitching	3
Case 26, UMI, FR1, Time offset = 0 ns, Frequency-domain Stitching	Yes
Case 26, UMI, FR1, Time offset = 0.5 ns, Frequency-domain Stitching	Yes
Case 26, UMI, FR1, Time offset = 1 ns, Frequency-domain Stitching	Yes
Case 26, UMI, FR1, Time offset = 2 ns, Frequency-domain Stitching	0.5
Case 26, UMI, FR1, Time offset = 5 ns, Frequency-domain Stitching	0.5

Simulation case (Horizontal Error)	Phase Shift between the two aggregated component carriers	Commercial horizontal accuracy requirements [1]m @[90]% are met - Yes/No. If no, provide performance gaps [m]	IIoT horizontal accuracy requirements of [0.2]m @[90]%are met - Yes/No. If no, provide performance gaps [m]	IIoT horizontal accuracy requirements of [0.5]m @[90]%are met -Yes/No. If no, provide performance gaps [m]
Case 27, InF FR1 DH ISD20, Link Quality, Freq. Agg. Of two 100MHz CCs with 1.8MHz Gap	0 degrees	23.4	24.2	23.9
	45 degrees	24.6	25.4	25.1
	90 degrees	24.5	25.3	25
Case 27, InF FR1 DH ISD20, Link Quality, Freq. Agg. Of two 100MHz CCs with 100MHz Gap	0 degrees	24.7	25.5	25.2
	45 degrees	24.4	25.2	24.9
	90 degrees	27.9	28.7	28.4
Case 27, InF FR1 SH ISD50, Link Quality, Freq. Agg. Of two 100MHz CCs with 1.8MHz Gap	0 degrees	2.4	3.2	2.9
	45 degrees	1.9	2.7	2.4
	90 degrees	2.4	3.2	2.9
Case 27, InF FR1 SH ISD50, Link Quality, Freq. Agg. Of two 100MHz CCs with 100MHz Gap	0 degrees	3.25	4.05	3.75
	45 degrees	3.26	4.06	3.76
	90 degrees	3.43	4.23	3.93

Simulation case (Horizontal Error)	Commercial horizontal accuracy requirements [1]m @[90]% are met - Yes/No. If no, provide performance gaps @[90]%	IIoT horizontal accuracy requirements of [0.2]m @[90]%are met - Yes/No. If no, provide performance gaps @[90]%	IIoT horizontal accuracy requirements of [0.5]m @[90]%are met -Yes/No. If no, provide performance gaps @[90]%
28 2*200MHz Perfect phase	Yes.	Yes.	Yes.
28 200MHz(baseline)	Yes.	Yes.	Yes.
29 2*200MHz Perfect phase	63%	62%	62%
29 200MHz(baseline)	62%	61%	61%
30 2*200MHz Perfect phase	Yes.	78%	83%
30 200MHz(baseline)	Yes.	66%	77%
31 2*200MHz Perfect phase	Yes.	Yes.	Yes.
31 200MHz(baseline)	Yes.	Yes.	Yes.
32 2*200MHz Perfect time	Yes.	78%	83%
32 200MHz(baseline)	Yes.	66%	77%
33 2*200MHz Perfect time	Yes.	Yes.	Yes.
33 200MHz(baseline)	Yes.	Yes.	Yes.

Case ID	Kinematic constraint condition	90%
Case 34 InF-SH, FR2, DL-TDOA, RANSAC	XY is unknown in the estimation. XY is unknown in the RMS calculation	0.049
	X is unknown in the estimation. X is unknown in the RMS calculation	0.024
	XY is unknown in the estimation. X is unknown in the RMS calculation	0.024
	Y is unknown in the estimation. Y is unknown in the RMS calculation	0.031
	XY is unknown in the estimation. Y is unknown in the RMS calculation	0.036
Case 35 InF-DH, FR2, DL-TDOA, RANSAC	XY is unknown in the estimation. XY is unknown in the RMS calculation	0.058
	X is unknown in the estimation. X is unknown in the RMS calculation	0.029
	XY is unknown in the estimation. X is unknown in the RMS calculation	0.034
	Y is unknown in the estimation. Y is unknown in the RMS calculation	0.038
	XY is unknown in the estimation. Y is unknown in the RMS calculation	0.044
Case 36 InH, FR2 DL-TDOA, RANSAC	XY is unknown in the estimation. XY is unknown in the RMS calculation	0.071
	X is unknown in the estimation. X is unknown in the RMS calculation	0.026
	XY is unknown in the estimation. X is unknown in the RMS calculation	0.028
	Y is unknown in the estimation. Y is unknown in the RMS calculation	0.044
	XY is unknown in the estimation. Y is unknown in the RMS calculation	0.053

Horizontal Positioning Error	Gain vs Rel.16 solution, @[90]%, [m]	Commercial horizontal accuracy requirements [1]m @[90]% are met - Yes/No. If no, provide performance gaps @[90]%
Case 37, UMI, FR1, RTT, With Delta Tau, Perfect Sync, No Timing Errors, AoA & UL PDP Enhancement	3.4	2.9
Case 38, UMI, FR1, DL-TDOA, With $\Delta\tau$, Perfect Sync, No Timing Errors, UL PDP Enhancement	1	7
Case 39, UMI, FR1, RTT, With Delta Tau, Perfect Sync, No Timing Errors, UL PDP Enhancement	4.3	3.7

Horizontal Positioning Error	Gain vs Rel.16 solution, @[90]%, [m]	IIoT horizontal accuracy requirements of [0.2]m @[90]% are met - Yes/No. If no, provide performance gaps @[90]%	IIoT horizontal accuracy requirements of [0.5]m @[90]% are met - Yes/No. If no, provide performance gaps @[90]%
Case 40, InF FR1 DH ISD20, 100MHz, LOS Genie + Link Quality	-0.009	Yes	Yes

8.2.2 Physical layer latency analysis for NR positioning enhancements

8.2.2.1 Observations from source [4]

Observations on NR positioning latency enhancements are provided in Table 8.2.2.1-1.

Table 8.2.2.1-1: NR positioning enhancements - physical layer latency performance summary [4]

Description Evaluation Case	L1 Latency, ms	Gain over R16, ms	Commercial requirements [100]ms are met Yes/No. If no, provide performance gaps	IIoT requirements of [10]ms are met Yes/No. If no, provide performance gaps	IIoT requirements of [100]ms are met Yes/No. If no, provide performance gaps
Case L101, UL E-CID w/ measurements available	6-26ms	0	Yes	Yes/No	Yes
Case L102, UL E-CID w/o measurements available	46-53.5ms	Negative	Yes	No	Yes

8.2.2.2 Observations from source [8]

Table 8.2.2.2-1: NR positioning enhancements - physical layer latency performance summary [8]

Description Evaluation Case	L1 Latency, ms	Gain over R16, ms	Commercial requirements [100]ms are met Yes/No. If No, provide performance gaps	IIoT requirements of [10]ms are met Yes/No. If No, provide performance gaps	IIoT requirements of [100]ms are met Yes/No. If No, provide performance gaps
Case 1, 15kHz, FR1, DL-TDOA	13.5	38	Yes	No (3.5ms gap)	Yes

8.2.2.3 Observations from source [5]

Observations on NR positioning latency enhancements are provided in Table 8.2.2.3-1.

Table 8.2.2.3-1: NR positioning enhancements - physical layer latency performance summary [5]

Description Evaluation Case	L1 Latency, ms	Gain over R16, ms	Commercial requirements [100]ms are met Yes/No. If no, provide performance gaps	IIoT requirements of [10]ms are met Yes/No. If no, provide performance gaps	IIoT requirements of [100]ms are met Yes/No. If no, provide performance gaps
[Case 7], [on-demand/aperiodic PRS]	44.5ms ~	19.5ms~		34.5ms~	
[Case 8], [on-demand/aperiodic MG]	27.5ms ~	36.5ms~		17.5ms~	
[Case 9], [Positioning BWP]	28.5ms ~	35.5ms~		18.5ms~	
[Case 10], [physical layer triggered]	44ms~	20ms~		32ms~	
[Case 11], [combination scheme]	5ms~	59ms~		Yes	
[Case 12] [idle/inactive]	27.3ms ~	58ms or 76.7ms		17.3ms	

8.2.2.4 Observations from source [10]

Observations on NR positioning latency enhancements are provided in Table 8.2.2.4-1.

Table 8.2.2.4-1: NR positioning enhancements - physical layer latency performance summary

Description Evaluation Case	L1 Latency, ms	Gain over R16, ms
Case 4, InF, FR1, R17, DL-TDOA/DL-AoD	3.8839 (L1 components) + 4 (L2/L3 components) = 8 (total)	0.6875 (L1 components) [32] (L2/L3 components) 121.07 (total)
Case 5, InF, FR1, R17, UL-TDOA/UL-AoA	1.9018 (L1 components) + 3 (L2/L3 components) = 5 (total)	0.8660 (L1 components) [13] (L2/L3 components) 13.7678 (total)
Case 6, InF, FR1, R17, Multi-RTT	4.1875 (L1 components) + 4 (L2/L3 components) = 8.2 (total)	3.1518 (L1 components) [41] (L2/L3 components) 132.6393 (total)

8.2.2.5 Observations from source [16]

The latency analysis for each enhancement scenario is summarized in the following table:

Description Evaluation Case	L1 Latency, ms	Gain over R16 (UE-assisted DL methods (Case 1)), ms
No measurement gap DL methods	16	17
Measurement gap activation/deactivation DL methods	24	09
On-demand DL PRS methods	22	11

8.2.2.6 Observations from source [17]

Observations on NR positioning latency enhancements are provided in Table 8.2.2.1.6-1.

Table 8.2.2.6-1: NR positioning enhancements - physical layer latency performance summary

Description Evaluation Case	Gain over R16, ms
Support Low-layer (e.g., unicast/group-common DCI, MAC-CE) triggering of DL/UL PRS transmission/muting/Location-Request for DL-only and DL/UL methods.	10 msec
Support DCI/MAC-CE triggering of Measurement gaps (MG) for the purpose of positioning measurements	>30 msec
Fast/real-time processing of short PRS instances: Support Enhanced PRS processing capabilities Support partially-staggered or no-staggered DL-PRS transmissions	>1.5 msec
Support Low-layer (e.g. UL MAC-CE or UCI) Measurement Reporting towards the serving gNB	2 msec

8.2.2.7 Observations from source [15]

Summary of latency performance analysis is provided in Table 8.2.2.7-1.

Table 8.2.2.7-1: NR positioning enhancements – latency analysis [15]

Description Evaluation Case	Assumptions	L1 Latency, ms (including preparation/processing time at higher layer)	L1 Latency, ms (excluding preparation/processing time at higher layer)
Case 1, DL- TDOA, DL-AOD [NW initiated, UE- A]	FR1, 15kHz # of symbols for PUSCH: 1~14 OS # of symbols for PDSCH: 2~14 OS	For UE capability-1: 49.12 ms ~ 198.12 ms For UE capability-2: 47.68 ms ~ 196.26 ms	For UE capability-1: 23.12ms ~ 167.12ms For UE capability-2: 21.68ms ~ 165.26ms
Case 2, DL- TDOA, DL-AOD [UE initiated, UE- A]	# of symbols for SRS: 2~12 OS	For UE capability-1: 41.41ms ~ 185.84ms For UE capability-2: 40.33ms ~ 184.55ms	For UE capability-1: 22.41ms ~ 165.34ms For UE capability-2: 21.33ms ~ 164.05ms
Case 3, UL- TDOA, UL-AOA [NW initiated, UE- A]	-Uplink switching gap is not configured. -No BWP switching -No overlapping symbols of the PUCCH and the scheduled PUSCH	For UE capability-1: 14.78 ms ~ 20.14 ms For UE capability-2: 14.42 ms ~ 19.57 ms	For UE capability-1: 0.78 ms ~ 2.64 ms For UE capability-2: 0.42 ms ~ 2.07 ms
Case 4, Multi-RTT [NW initiated, UE- A]	-No overlapping symbols of the scheduling PDCCH and the scheduled PDSCH	For UE capability-1: 63.9 ms ~ 215.76 ms For UE capability-2: 62.1 ms ~ 213.33 ms	For UE capability-1: 23.9 ms ~ 169.76 ms For UE capability-2: 22.1 ms ~ 167.33ms
Case 5, E-CID [NW initiated, UE- A]	*Note: The maximum latency for PDSCH/PUSCH transmission is assumed as one slot excluding preparation time. Total values may change when the information size related with LPP message is changed.	For UE capability-1: 14.56 ms ~ 17.56 ms For UE capability-2: 13.84 ms ~ 16.63 ms	For UE capability-1: 1.56ms ~ 3.56ms For UE capability-2: 0.84ms ~ 2.63ms

8.3 Efficiency analysis for NR positioning enhancements

In this report, Network efficiency and UE efficiency is evaluated either via analytically or via simulations. This clause presents the observations made by sources. Detailed results can be found in annex C.3.

8.3.1 Network efficiency analysis for NR positioning enhancements

8.3.1.1 Observations from source [5]

PRS resource utilization with different periodicities were evaluated

- In FR1, for 20 ms DL PRS periodicity and MG periodicity, 3ms MGL, 30 kHz subcarrier spacing, comb 6 and 6 symbols per PRS resource, 18 positioning sites and 1 beams per site, PRS resource utilization is 3.21% while the MGL/MGRP (UE overhead) is 15%.
- In FR2, for 20 ms DL PRS periodicity, 20ms for MGL and MGRP, 120 kHz subcarrier spacing, comb 6 and 6 symbols per PRS resource, 18 positioning sites and 64 beams per site, PRS resource utilization is 51.42% while the MGL/MGRP (UE overhead) is 100%

The network and device efficiency of aperiodic PRS is multiple of the number of activations.

8.3.1.2 Observations from source [18]

Summary of cyclic shift enhancements SRS is provided in Table 8.3.1.2.-1.

Table 8.3.1.2-1: NR positioning enhancements - Cyclic shift SRS enhancements [18]

Scenario	Rel-16/ Rel-17 enhancements	COMB	nbSym	Cyclic shift range	max number of CSs	Number of simultaneous UEs of CS separated	Improvement factor vs Rel16
Umi	CS enhancement	4	4	fftlength	48	8	4
	Rel-16	4	4	fftlength/KTC	12	2	
Umi	CS enhancement	8	8	fftlength	48	8	8
	Rel-16	8	8	fftlength/KTC	6	1	
InF	CS enhancement	2	1	fftlength/KTC	8	8	-
	Rel-16	2	1	fftlength/KTC	8	8	

Summary of multi-port SRS evaluation is provided in Table 8.3.1.2.-2.

Table 8.3.1.2-2: NR positioning enhancements - SRS resource utilization w.r.t to the number of antenna ports:

Scenario	Rel-17 enhancements	# of Tx Beams	COMB	nbSym	OFDM symbols per UE	Capacity per UE	Improvement factor vs Rel16
FR1-Umi	2-ports	2	4	4	4	1	2
	Rel-16	2	4	4	8	2	
FR1-InF	2-ports	2	2	1	1	0,5	2
	Rel-16	2	2	1	2	1	
FR2-Umi	4-ports	4	8	8	8	2	4
	Rel-16	4	8	8	32	8	
FR2-InF (SCS=120kHz)	4-ports	4	4	4	4	1	4
	Rel-16	4	4	16	16	4	

8.3.2 UE efficiency analysis for NR positioning enhancements

8.3.2.1 Observations from source [4]

Observations on NR positioning UE efficiency enhancements are provided in Table 8.3.2.1-1.

Table 8.3.2.1-1: NR positioning enhancements – UE efficiency summary [4]

Description Evaluation Case	Power consumption	Power saved
Case P1: IDLE/INACTIVE state in every 1.28s	26392	7.2% to Case P2 30.4% to Case P3
Case P2: CONNECTED state inside on-duration in every 1.28s	28432	-
Case P3: CONNECTED state outside on-duration in every 1.28s	37936	-
Case P4: IDLE/INACTIVE state in every 1.28s	11910	39.6% to Case P5
Case P5: CONNECTED state outside on-duration in every 1.28s	19712	-

8.3.2.2 Observations from source [5]

Observations of UE efficiency for power consumption

Table 8.3.2.2-1: NR positioning enhancements – power consumption performance in connected state [5]

Power saving scheme description	Average power consumption (power unit)	Power reduction compared to baseline	Note
PRS measurement impacted by DRX	53.5625(baseline) 2 PRS occasions every DRX cycle(160ms)	-	In this case, PRS period=80ms DRX cycle=160ms If PRS measurement is impacted by DRX, UE is only expected to measure PRS in DRX active time.
	35.2500 1 PRS occasion every DRX cycle (160ms)	34.19%	
Extending PRS period	35.2500(baseline) PRS period=160ms	-	-
	27.4844 PRS period=320ms	22.03%	
	23.6016 PRS period=640ms	33.05%	
Concentrated PRS distribution	43.3937(baseline) 4 distributed PRS occasion every 160ms	-	In this case, the duration of concentrated PRS distribution is 5ms with 4ms PRS length and 1ms MG switching time. While for distributed PRS, we divide the concentrated PRS occasion of 4ms (baseline) into 4 PRS occasions with 1ms, and the adjacent PRS occasions are separated by 40ms.
	35.2500 1 concentrated PRS occasion every 160ms	18.77%	
Adding PRS-MTC window	35.2500(baseline) without PRS-MTC PRS occasion duration=4ms	-	-
	28.0313 PRS-MTC to limit PRS measurement PRS occasion duration=2ms	20.48%	-
Reducing number of TRPs to be measured	35.2500(baseline) Number of TRPs=8	-	-
	32.2500 Number of TRPs=4	8.51%	
Reducing number of positioning frequency layers to be measured	82.4688 (baseline) Number of FLs=4	-	-
	52.0313 Number of FLs=2	36.91%	
	35.2500 Number of FLs=1	57.26%	

Table 8.3.2.2-2: NR positioning enhancements – power consumption comparison in idle state and connected state [5]

Power saving scheme description	Average power consumption (power unit)	Power reduction compared to baseline	Additional assumptions	Note
1. Connected state measurement and report	11.1367(baseline)	-	1. UE starts positioning from idle state 2.LPP/RRC procedures for positioning are ignored. 3. Only one shot positioning measurement and report considered. 4.Once the positioning report is completed, the RRC connection is released 5. Measurement/report cycle is equal to idle state (1280ms). 6. The power unit for PRS measurement in connected state is equal to PRS bandwidth in idle state 7. Paging occasion power is equivalent to 'PDCCH+PDSCH', considering it may lead to RRC state transition	Considering that some assumptions are made to simplify power consumption evaluation, such as ignoring complicated steps for LPP procedures, aligning the bandwidth and period with idle state measurement, it will consume more power when positioning in the connected state in general.
2. Idle state measurement and connected state report	10.3246	7.29%	UE switches to connected mode to report. Once the positioning report is completed, the RRC connection is released	
3. Idle state measurement and idle state report	5.7488	48.38%	-	

The UE efficiency of periodic PRS and MG and on-demand MG with concentrated PRS in FR2 were evaluated:

- For 20 ms DL PRS periodicity and MGRP, 20ms for MGL, 120 kHz subcarrier spacing, comb 6 and 6 symbols per PRS resource, 18 positioning sites and 64 beams per site, the UE efficiency(MGL/MGRP) is 100%
- For 160 ms DL PRS periodicity and MGRP, 20ms for MGL, 120 kHz subcarrier spacing, comb 6 and 6 symbols per PRS resource, 18 positioning sites and 64 beams per site, the UE efficiency(MGL/MGRP) is 12.5%
- For on-demand MG with concentrated PRS, the range of UE efficiency is 0%-40% depends on the configuration of on-demand MG and PRS

The UE efficiency of periodic PRS and MG and positioning BWP without MG in FR2 were evaluated:

- For 20 ms DL PRS periodicity and MG, 20ms for MGL, 120 kHz subcarrier spacing, comb 6 and 6 symbols per PRS resource, 18 positioning sites and 64 beams per site, the UE efficiency(MGL/MGRP) is 100%

- For 160 ms DL PRS periodicity and MGRP, 20ms for MGL, 120 kHz subcarrier spacing, comb 6 and 6 symbols per PRS resource, 18 positioning sites and 64 beams per site, the UE efficiency(MGL/MGRP) is 12.5%
- For 20 ms DL PRS periodicity and without MG, the UE efficiency is 30% only depends on DL PRS symbols
- For 160 ms DL PRS periodicity and without MG, the UE efficiency is 1.88% only depends on DL PRS symbols

8.4 Summary of performance evaluations

Performance analysis of baseline I-IoT InF scenarios shows that InF-SH scenario (Scenario 1) is characterized by high probability of LOS links. In InF-DH (Scenario 2) the probability of LOS links is reduced substantially while probability of NLOS links is increased accordingly.

For the case without modeling synchronization and gNB/UE TX/RX timing errors in the InF-SH scenario (Scenario 1).

- Based on the results provided by a majority of sources, sub-meter level @ 90% of horizontal positioning accuracy is achieved by Rel.16 solutions.
- For horizontal accuracy, results were provided by 13 sources([4], [6], [7], [8], [9], [12], [13], [14], [19], [20], [17], [5], [10]) out of 17 sources for FR1 and by 9 sources ([4], [6], [7], [8], [14], [20], [17], [5], [10]) out of 17 for FR2
- For NR positioning evaluations in FR1 band, the following is observed with respect to horizontal positioning accuracy:
 - (a) Accuracy of $\leq 0.2\text{m}$ @ 90% is achieved in contributions from 4 sources ([8], [20], [5],[17]) and is not achieved in contributions from 9 sources ([4], [6], [7], [9], [12], [13], [14], [19], [10])
 - (b) Accuracy of $\leq 0.5\text{m}$ @ 90% is achieved in contributions from 6 sources ([4], [8], [20], [17], [5], [10])and is not achieved in contributions from 7 sources ([6], [7], [9], [12], [13], [14], [19])
- For NR positioning evaluations in FR2 band, the following is observed with respect to horizontal positioning accuracy:
 - (a) Accuracy of $\leq 0.2\text{m}$ @ 90% is achieved in contributions from [7] ([4],[7], [8], [20], [17], [5], [10])sources and is not achieved in contributions from 2 sources ([6], [14])
 - (b) Accuracy of $\leq 0.5\text{m}$ @ 90% is achieved in contributions from 9 sources ([4], [6], [7], [8], [14], [20], [17], [5] ,[10]) and is not achieved in contributions from 0 sources
- For vertical accuracy, results were provided by 4 sources ([7], [8], [5], [10]) out of 17 for FR1 and by 4 sources ([7], [8], [17], [10]) out of 17 for FR2 band
- For NR positioning evaluations in FR1 band, the following is observed with respect to vertical positioning accuracy:
 - (a) Accuracy of $\leq 1\text{m}$ @ 90% is achieved in contribution from 2 sources ([7], [5]) and is not achieved from 2 sources ([8], [10])
- For NR positioning evaluations in FR2 band, the following is observed with respect to vertical positioning accuracy:
 - (a) Accuracy of $\leq 1\text{m}$ @ 90% is achieved in contribution from 4 sources ([7], [8], [17], [10]) [and is not achieved by 0 sources]

For the case without modeling synchronization and gNB/UE TX/RX timing errors in the baseline InF-DH scenario (Scenario 2), including evaluations with variable gNB/UE heights for vertical accuracy

- Based on the results provided by a majority of sources, sub-meter level @ 90% of horizontal positioning accuracy is not achieved by Rel.16 based solutions.

- For horizontal accuracy, results were provided by 14 sources ([4], [6], [7], [8], [9], [12], [13], [14], [19], [20], [17], [5], [10], [18]) out of 17 for FR1 and by 9 sources ([4], [6], [7], [8], [14], [20], [17], [5], [10]) out of 17 for FR2
- For NR positioning evaluations in FR1 band, the following is observed with respect to horizontal positioning accuracy:
 - (a) Accuracy of $\leq 0.2\text{m}$ @ 90% is achieved in contribution from [3] sources ([8],[17],[5]) and is not achieved in contributions from 11 sources ([4], [6], [7], [9], [12], [13], [14], [19], [20], [10], [18])
 - (b) Accuracy of $\leq 0.5\text{m}$ @ 90% is achieved in contributions from 4 sources ([6], [8], [17], [5]) and is not achieved in contributions from 10 sources ([4], [7], [9], [12], [13], [14], [19], [20], [10], [18])
- For NR positioning evaluations in FR2 band, the following is observed with respect to horizontal positioning accuracy:
 - (a) Accuracy of $\leq 0.2\text{m}$ @ 90% is achieved in contributions from 4 sources ([6], [17], [5], [8]) and is not achieved in contributions from 6 sources ([4], [7], [14], [20], [10])
 - (b) Accuracy of $\leq 0.5\text{m}$ @ 90% is achieved in contributions from 4 sources ([6], [17], [5], [8]) and is not achieved in contributions from 6 sources ([4], [7], [14], [20], [10])
- For vertical accuracy, results were provided by 6 sources ([7], [8], [5], [10], [4], [18]) out of 17 for FR1 and by 4 sources ([7], [8], [10], [4]) out of 17 for FR2 band
- For NR positioning evaluations in FR1 band, the following is observed with respect to vertical positioning accuracy:
 - (a) Accuracy of $\leq 1\text{m}$ @ 90% is achieved in contribution from 2 sources ([8], [5]) and is not achieved from 4 sources ([7], [10], [4], [18])
- For NR positioning evaluations in FR2 band, the following is observed with respect to vertical positioning accuracy:
 - (a) Accuracy of $\leq 1\text{m}$ @ 90% is achieved in contribution from 1 source ([4]) and is not achieved from [3] sources ([7], [8], [10])

For the issues related to mitigating effects of multipath/NLOS for positioning

- Evaluation results for LOS/NLOS identification, outlier rejection, NLOS mitigation based on triangle inequality algorithms in indoor factory scenarios were provided by 12 sources ([12], [9], [5], [10], [17], [7], [4], [19], [13], [14], [18], [20]) out of 17 sources
- NR positioning utilizing LOS/NLOS identification, outlier rejection, NLOS mitigation based on triangle inequality algorithms improve performance of positioning accuracy with respect to solutions that do not apply these techniques
- From the evaluations,
 - 9 sources ([9], [10], [7], [4], [19], [13], [14], [18], [20]) evaluated LOS/NLOS identification with additional specification changes relative to Rel.16 solutions
 - 2 sources ([5], [17]) evaluated outlier rejection algorithm (implementation-based algorithm that can be applied for Rel.16 solutions without specification changes)
 - 1 source ([12]) evaluated NLOS mitigation using triangle-based inequality algorithm (implementation-based algorithm that can be applied for Rel.16 solutions without specification changes)
- Comparative analysis of LOS/NLOS identification with specification changes vs implementation based methods (outlier rejection algorithms) was done by 6 sources ([10], [4], [5], [17], [7], [12])
 - Three sources ([10], [4], [7]) observe that NR positioning based on LOS/NLOS identification outperforms NR positioning utilizing outlier rejection
 - Three sources ([5], [17], [12]) observe that NR positioning utilizing outlier rejection outperforms NR positioning utilizing LOS/NLOS identification

For issues related to gNB/UE TX/RX timing errors

- Evaluation results of gNB/UE TX/RX timing errors (as per the optional model) are provided by 7 sources ([4], [7], [17], [10], [8], [20], [5]) out of 17 sources)
- Summary of results is provided in tables B.1-1 to B.1-4

For the issues related to aggregation of DL positioning frequency layers:

- Evaluation results for aggregation of DL positioning frequency layers were provided by 5 sources ([10], [17], [4], [22], [20]) out of 17.
- Aggregation of NR positioning frequency layers improves positioning accuracy under certain scenarios, configurations, and assumptions on modelled impairments such as: bandwidth and spacing of aggregated layers, timing offset and frequency offset over frequency layers, phase discontinuity and possible amplitude imbalance.
 - One source ([4]) observes that aggregation with phase continuity can help to improve the positioning accuracy, and discontinuous aggregation can approach the performance of contiguous aggregation with the same frequency span
 - One source ([10]) has shown that aggregation of frequency layers (without modeling impairments) improves the positioning accuracy for intra-band contiguous configuration and that further study is needed for other cases including impairments
 - One source ([20]) has observed that PRS aggregation shows potential gains without modeling phase error, but these gains are lost when the phase error between CCs becomes too large
 - One source ([17]) has analyzed aggregation of 2 and 4 frequency layers for different channel spacings, time and phase offset across frequency layers
 - One source ([22]) has analyzed aggregation of 2 frequency layers for different time offset values and observed that:
 - For the case without impairments modeling, aggregation of multiple DL positioning frequency layers 50MHz+50MHz, performance target [0.2m @ 90%] cannot be achieved in both InF-SH and InF-DH.
 - For the case without impairments modeling, aggregation of multiple DL positioning frequency layers 50MHz+50MHz, the performance is worse than 100MHz but better than 50MHz.
 - The performance of aggregation of frequency layers degrades if timing offset is increased

For issues related to physical layer latency for Rel.16 DL-TDOA/DL-AOD

- Summary of results is provided in table B.2-1
- Summary of physical layer latency for Rel.16 DL-TDOA/DL-AOD UE-assisted NR positioning in FR1 was provided by 11 sources
- Summary of physical layer latency for Rel.16 DL-TDOA/DL-AOD UE-assisted NR positioning in FR2 was provided by 5 sources
- For evaluation in FR1,
 - results from 11 sources out of 11 sources ([17], [4], [7], [5], [11], [15], [8], [13], [12], [16], [10]) show that minimum estimated physical layer latency for Rel.16 DL-TDOA/DL-AOD UE-assisted NR positioning exceeds 10ms
 - results from [2] ([7], [10]) sources out of 11 sources ([17], [4], [7], [5], [11], [15], [8], [13], [12], [16], [10]) show that minimum estimated physical layer latency for Rel.16 DL-TDOA/DL-AOD UE-assisted NR positioning exceeds 100ms
- For evaluation in FR2,
 - results from 5 sources out of 5 sources ([7], [5], [11], [12],[13]) show that minimum estimated physical layer latency for Rel.16 DL-TDOA/DL-AOD UE-assisted NR positioning exceeds 10ms

- results from 2 ([7], [5]) sources out of 4 sources ([7], [5], [11], [12]) show that minimum estimated physical layer latency for Rel.16 DL-TDOA/DL-AOD UE-assisted NR positioning exceeds 100ms
- The following list provides the major physical layer latency components for Rel.16 DL TDOA/DL-AOD UE-assisted NR Positioning
 - DL PRS alignment, transmission, measurement (including processing time) and report delay
 - Measurement gap request, configuration and alignment time
 - UE/gNB higher layer (LPP/RRC) processing times

For issues related to physical layer latency for Rel.16 UL-TDOA/UL-AOA

- Summary of results is provided in table B.2-2
- Summary of physical layer latency for Rel.16 UL-TDOA/UL-AOA NR positioning in FR1 was provided by 8 sources ([4], [5], [15], [8], [13], [12], [16], [10])
- Summary of physical layer latency for Rel.16 UL-TDOA/UL-AOA NR positioning in FR2 was provided by 2 sources ([5], [12])
- For evaluation in FR1,
 - results from [3] sources ([4], [8], [13]) out of 8 sources ([4], [5], [15], [8], [13], [12], [16], [10]) show that minimum estimated physical layer latency for Rel.16 UL-TDOA/UL-AOA NR positioning does not exceed 10ms
 - results from 8 sources out of 8 sources ([4], [5], [15], [8], [13], [12], [16], [10]) show that minimum estimated physical layer latency for Rel.16 UL-TDOA/UL-AOA NR positioning does not exceed 100ms
- For evaluation in FR2,
 - results from 2 sources out of 2 sources ([5], [12]) show that minimum estimated physical layer latency for Rel.16 UL-TDOA/UL-AOA NR positioning exceeds 10ms
 - results from [1] ([12]) sources out of 2 sources ([5], [12]) show that minimum estimated physical layer latency for Rel.16 UL-TDOA/UL-AOA NR positioning does not exceed 100ms
- The following list provides the major physical layer latency components for Rel.16 UL-TDOA/UL-AOA NR Positioning
 - SRS for positioning processing time
 - SRS for positioning alignment time (depends on periodic or aperiodic SRS for positioning)
 - gNB higher layer processing delays (RRC/ NRPPa processing times)

For issues related to physical layer latency for Rel.16 Multi-RTT

- Summary of results is provided in table B.2-3
- Summary of physical layer latency for Rel.16 Multi-RTT UE-assisted NR positioning in FR1 was provided by 6 sources ([17], [4], [5], [15], [16], [10])
- Summary of physical layer latency for Rel.16 Multi-RTT UE-assisted NR positioning in FR2 was provided by 0 sources
- For evaluation in FR1,
 - results from 6 sources ([17], [4], [5], [15], [16], [10]) out of 6 sources ([17], [4], [5], [15], [16], [10]) show that minimum estimated physical layer latency for Rel.16 Multi-RTT UE-assisted NR positioning exceeds 10ms
 - results from 4 sources ([17], [4], [5], [16]) out of 6 sources ([17], [4], [5], [15], [16], [10]) show that minimum estimated physical layer latency for Rel.16 Multi-RTT UE-assisted NR positioning does not exceed 100ms
- The following list provides the major physical layer latency components for Rel.16 Multi-RTT UE-assisted NR positioning

- DL PRS alignment, transmission, measurement time and report delay
- Measurement gap request, configuration, alignment time
- SRS for positioning processing time
- SRS for positioning alignment time (depends on periodic or aperiodic SRS for positioning)
- UE/gNB higher layer (LPP/RRC/NRPPa) processing times

For issues related to physical layer latency for Rel.16 E-CID NR positioning

- Summary of results is provided in table B.2-4
- Summary of physical layer latency for Rel.16 E-CID NR positioning in FR1 was provided by [3] sources ([4], [7], [15])
- Summary of physical layer latency for Rel.16 E-CID NR positioning in FR2 was provided by 0 sources
- For evaluation in FR1,
 - results from 2 sources ([7], [15]) out of 3 sources ([4], [7], [15]) show that minimum estimated physical layer latency for Rel.16 E-CID NR positioning exceeds 10ms
 - results from [3] sources ([4], [7], [15]) out of 3 sources ([4], [7], [15]) show that minimum estimated physical layer latency for Rel.16 E-CID NR positioning does not exceed 100ms
- The following list provides the major physical layer latency components for Rel.16 E-CID NR positioning
 - Higher layer signaling processing

For issues related to physical layer latency for Rel.16 DL-only UE-based NR positioning

- Summary of results is provided in table B.2-5
- Summary of physical layer latency for Rel.16 DL-only UE-based NR positioning in FR1 was provided by 6 sources ([17], [4], [5], [11], [12], [16])
- Summary of physical layer latency for Rel.16 DL-only UE-based NR positioning in FR2 was provided by 2 sources ([5], [11])
- For evaluation in FR1,
 - results from 4 sources ([4], [5], [12], [16]) out of 6 sources ([17], [4], [5], [11], [12], [16]) show that minimum estimated physical layer latency for Rel.16 DL-only UE-based NR positioning exceeds 10ms
 - results from 6 sources out of 6 sources ([17], [4], [5], [11], [12], [16]) show that minimum estimated physical layer latency for Rel.16 DL-only UE-based NR positioning does not exceed 100ms
- For evaluation in FR2,
 - results from 2 sources out of 2 sources ([5], [11]) show that minimum estimated physical layer latency for Rel.16 DL-only UE-based NR positioning exceeds 10ms
 - results from [1] ([5]) sources out of 2 sources ([5], [11]) show that minimum estimated physical layer latency for Rel.16 DL-only UE-based NR positioning exceeds 100ms
- The following list provides the major physical layer latency components for Rel.16 DL-only UE-based NR positioning
 - DL PRS alignment, transmission, measurement time and, if requested, report delay
 - Measurement gap request, configuration, alignment time
 - Higher layer (LPP/RRC) processing times

For issues related to higher layer latency for Rel.16 DL-TDOA/DL-AOD

- Summary of results is provided in table 8.1.3.1-1

For issues related to higher layer latency for Rel.16 UL-TDOA/UL-AOA

- Summary of results is provided in table 8.1.3.2-1

For issues related to higher layer latency for Rel.16 Multi-RTT

- Summary of results is provided in table 8.1.3.3-1

For issues related to higher layer latency for Rel.16 NR E-CID positioning

- Summary of results for Downlink NR E-CID is provided in table 8.1.3.4-1
- Summary of results for Uplink NR E-CID is provided in table 8.1.3.4-2

For the case without modeling synchronization and gNB/UE TX/RX timing errors in the UMa scenario

- Based on the results provided, 10 m level @ 90% of horizontal positioning accuracy is achieved by Rel.16 in UMa scenario
- Results were provided by 2 sources ([20], [17]) out of 17 for FR1 band
- For NR positioning evaluations for UMa scenario in FR1 band, the following is observed with respect to horizontal positioning accuracy:
 - (a) Accuracy of $\leq 1\text{m}$ @ 80% is achieved for the outdoor UEs in contributions from 1 source ([17]) out of 2 sources ([20], [17]) in the scenario without absolute time of arrival modelling. Zero sources met an accuracy of $\leq 1\text{m}$ @ 90%.
 - (b) Accuracy of $\leq 10\text{m}$ @ 90% is achieved for the outdoor UEs in contributions from 2 sources ([20], [17]) out of 2 sources in the scenario without absolute time of arrival modelling
 - (c) Accuracy of $\leq 10\text{m}$ @ 90% is achieved for the indoor UEs in contributions from 1 source ([20]) out of 2 sources in the scenario without absolute time of arrival modelling

For the case without modeling synchronization and gNB/UE TX/RX timing errors in the UMi scenario

- Results were provided by 4 sources ([13], [20], [17], [18]) out of 17 for FR1 band
- For NR positioning evaluations for UMi scenario in FR1 band, the following is observed with respect to horizontal positioning accuracy:
 - (a) Accuracy of $\leq 1\text{m}$ @ 90% is achieved in contributions from 2 sources ([20], [17]) and is not achieved from 2 sources ([13], [18]) in the scenario without absolute time of arrival modelling
Accuracy of $\leq 1\text{m}$ @ 90% is not achieved from 2 sources ([17], [18]) in a scenario with absolute time of arrival modelling
- For NR positioning evaluations for UMi scenario in FR2 band, the following is observed with respect to horizontal positioning accuracy:
 - (b) Accuracy of $\leq 1\text{m}$ @ 90% is achieved in contributions from 1 source ([17]) in the scenario without absolute time of arrival modelling.

For the case without modeling synchronization and gNB/UE TX/RX timing errors in the IOO scenario

- Based on the results provided by a majority of the sources, 1 m level @ 90% of horizontal positioning accuracy is achieved by Rel.16 in IOO scenario
- Results were provided by 5 sources ([8], [13], [14], [20], [23]) out of 17 for FR1 and 5 sources ([8], [14], [20], [17], [23]) out of 17 for FR2 band
- For NR positioning evaluations for IOO scenario in FR1 band, the following is observed with respect to horizontal positioning accuracy:
 - (a) Accuracy of $\leq 1\text{m}$ @ 90% is achieved in contributions from 4 sources ([8], [14], [20], [23]) and is not achieved from 1 source ([13]) in the scenario without absolute time of arrival modelling
 - (b) Accuracy of $\leq 1\text{m}$ @ 90% is achieved from 1 source ([23]) in a scenario with absolute time of arrival modelling
- For NR positioning evaluations for IOO scenario in FR2 band, the following is observed with respect to horizontal positioning accuracy:
 - (a) Accuracy of $\leq 1\text{m}$ @ 90% is achieved in contributions from 5 sources ([8], [14], [20], [17], [23]) in the scenario without absolute time of arrival modelling

- (b) Accuracy of $\leq 1\text{m}$ @ 90% is achieved from 1 source ([23]) in a scenario with absolute time of arrival modelling

The results for the UE efficiency (power saving) in the RRC_IDLE/RRC_INACTIVE states were analyzed by 2 sources ([4], [5]) out of 17 sources (assumptions may be different between the different sources)

- In one source ([4]), the following observations were made:
 - RRC_IDLE/RRC_INACTIVE state positioning can save about 7%-40% power consumption compared to C-DRX configuration
- In one source ([5]), the following observations were made:
 - Positioning report in the RRC_IDLE state can provide 44.32 % of power saving gain compared to the report in the RRC_CONNECTED state
 - Positioning measurement and report in the RRC_IDLE state can provide at least 48.38 % of power saving gain compared to the measurement and report in the RRC_CONNECTED state

The results for the PRS resource utilization were analyzed by 3 sources ([4], [5], [8]) out of 17 sources

- In one source ([4]), the PRS resource utilization was evaluated for the case of 160 ms DL PRS periodicity, 30 kHz subcarrier spacing, and 12, 4, and 1 symbol per PRS resource:
 - PRS with 12, 4, and 1 symbol has positioning resource utilization of 2.14 %, 0.714 %, and 0.179 %, respectively
- In one source ([5]), the PRS resource utilization was evaluated:
 - In FR1, for 20 ms DL PRS periodicity and MG periodicity, 3ms MGL, 30 kHz subcarrier spacing, comb 6 and 6 symbols per PRS resource, 18 positioning sites and 1 beams per site, PRS resource utilization is 3.21% while the MGL/MGRP (UE overhead) is 15%.
 - In FR2, for 20 ms DL PRS periodicity, 20ms for MGL and MGRP, 120 kHz subcarrier spacing, comb 6 and 6 symbols per PRS resource, 18 positioning sites and 64 beams per site, PRS resource utilization is 51.42% while the MGL/MGRP (UE overhead) is 100%
 - It was observed by the source that the network and device efficiency can be improved by on-demand PRS (assuming the same latency) compared to periodic PRS
- In one source ([8]), the PRS resource utilization was evaluated for the case of 20 ms DL PRS periodicity, 30 kHz subcarrier spacing, and 12 symbols per PRS resource:
 - PRS with 12 symbols has positioning resource utilization of 2.1 %.

9 Positioning integrity and reliability

9.1 Integrity Overview – Background Information

9.1.1 Integrity Concepts

The ability to navigate safely means users must trust their estimated position with a high degree of confidence. The trustworthiness of position estimates is the study of positioning integrity, which is adapted from TR 22.872 [30] as follows:

Positioning Integrity: A measure of the trust in the accuracy of the position-related data provided by the positioning system and the ability to provide timely and valid warnings to the LCS client when the positioning system does not fulfil the condition for intended operation.

Positioning integrity monitoring¹ is already supported by GNSS service providers, but there is no standard for expanding the ecosystem of connected devices which can benefit from positioning integrity. This study investigates new integrity assistance data and procedures to be considered in LPP and associated specifications, to assist in quantifying positioning integrity for the positioning system.

¹ A monitor is used to detect the feared events that occur more frequently than is acceptable to meet the TIR, i.e., the monitor's purpose is to reduce the likelihood that feared events go undetected.

9.1.1.1 Accuracy and Integrity

To understand the necessity of introducing the concept of positioning integrity, it is important to understand how it differs from the more familiar concept of Accuracy.

Positioning accuracy and positioning integrity are related but separate concepts, and for many use cases, accuracy alone is insufficient to meet the requirements. Positioning devices and services are typically designed to report the distribution of errors that characterize the overall system performance, which is often specified as an error percentile representing the accuracy. For example, a road vehicle with an embedded UE positioning client may report a lane-level accuracy of <50cm 95th percentile. In this case, the UE is indicating that, based on all the computed positions, its estimated accuracy is better than 50 cm, 95% of the time. For the remaining 5%, the position error is unknown. In fact, these errors might reach 10s or 100s of meters due to multiple different error sources. The 5% of errors are essentially unbounded without any way to reliably validate their distribution. In the case of GNSS, these errors could include constellation geometry (i.e., Dilution of Precision), sharp atmospheric gradients or irregularities, and local receiver effects such as high measurement noise or multipath.

Each time a position is provided, positioning integrity can be used to quantify the trust on the provided position. Positioning integrity is therefore a method of bounding these errors and this can be done to a much higher confidence. For example, a Target Integrity Risk (TIR) of $10^{-7}/\text{hr}$ translates to a 99.99999% probability that no hazardous misleading outputs occurred in a given hour of operation. The TIR sets the target for determining which feared events need to be monitored in order to meet the specified Alert Limit (AL) at this level of probability. A lower TIR introduces a wider range of threats (i.e., feared events) that need to be monitored to improve confidence in the estimated position. Erroneous position estimates which do not meet the positioning integrity criteria can then be omitted in the final positioning solution, allowing only the valid position estimates to be utilized, which also leads to higher accuracy.

9.1.1.2 Integrity Key Performance Indicators (KPIs)

The following KPIs for positioning integrity are defined for the study:

Target Integrity Risk (TIR): The probability that the positioning error exceeds the Alert Limit (AL) without warning the user within the required Time-to-Alert (TTA).

NOTE: The TIR is usually defined as a probability rate per some time unit (e.g., per hour, per second or per independent sample).

Alert Limit (AL): The maximum allowable positioning error such that the positioning system is available for the intended application. If the positioning error is beyond the AL, the positioning system should be declared unavailable for the intended application to prevent loss of positioning integrity.

NOTE: When the AL bounds the positioning error in the horizontal plane or on the vertical axis then it is called Horizontal Alert Limit (HAL) or Vertical Alert Limit (VAL), respectively.

Time-to-Alert (TTA): The maximum allowable elapsed time from when the positioning error exceeds the Alert Limit (AL) until the function providing positioning integrity announces a corresponding alert.

Integrity Availability: The integrity availability is the percentage of time that the PL is below the required AL.

The relationship between the KPIs and the Protection Level (PL), and their impacts on the positioning solution are further examined below.

9.1.1.3 Integrity Protection Level (PL)

The Protection Level (PL) is a real-time upper bound on the positioning error at the required degree of confidence, where the degree of confidence is determined by the TIR probability.

The PL is defined as follows:

Protection Level: The PL is a statistical upper-bound of the Positioning Error (PE) that ensures that, the probability per unit of time of the true error being greater than the AL and the PL being less than or equal to the AL, for longer than the TTA, is less than the required TIR, i.e., the PL satisfies the following inequality:

$$\text{Prob per unit of time } [(PE > AL) \ \& \ (PL \leq AL)] \text{ for longer than TTA} < \text{required TIR}$$

NOTE: When the PL bounds the positioning error in the horizontal plane or on the vertical axis then it is called Horizontal Protection Level (HPL) or Vertical Protection Level (VPL) respectively.

NOTE: A specific equation for the PL is not specified as this is implementation-defined. For the PL to be considered valid, it must simply satisfy the inequality above.

The PL is used to indicate the positioning system availability, as when the PL is greater than the AL, the system is considered unavailable (see Stanford Diagram below). The PL establishes a more rigorous upper bound on the positioning error by taking into consideration the additional feared events which have a lower occurrence (i.e., lower TIR) compared to the nominal events considered in the standard accuracy estimate alone. The lower the TIR, the more feared events that need to be considered.

Fault feared events are those which are intrinsic to the positioning system and typically caused by the malfunction of an element of the positioning system (e.g., constellation or ground network failures). Fault-free feared events occur when the positioning system inputs are erroneous, but the event is not caused by a malfunction of the positioning system. In the GNSS context for example, fault-free feared events include nominal effects experienced every day such as poor satellite geometry, larger atmospheric gradients, and signal interruption, all of which can degrade positioning performance without causing the system to fail. A common limitation of existing industry functional safety standards, as summarized in [31], is that only the fault conditions are considered. In practice, however, the fault-free conditions also have a material contribution to the total integrity risk budget and must therefore be monitored.

The PL is necessary to ensure all potential faults and fault-free events down to the required TIR are considered. It bounds the tails of the distribution with higher certainty (per unit of time) and provides a measure for ensuring only those positions whose positioning integrity has been validated within the TIR are included in the final positioning solution. By contrast, the standard accuracy estimate only considers a subset of feared events up to a nominal percentile (e.g., 2-sigma, 95%), based on the entire distribution of estimated position errors.

9.1.1.4 Relationship between the PL and KPIs

The TIR is a design constraint for a positioning system and represents the probability that a positioning error exceeds the AL, but the positioning system fails to alert the user within the required period of time (i.e., TTA). In practice, the TIR is very small. For example, $<10^{-7}/\text{hr}$ TIR translates to one failure permitted every 10 million hours (equivalent to 1142 years approximately).

Positioning integrity system failures are known as Integrity Events and integrity events occur when the positioning system outputs Hazardous Misleading Information (HMI). HMI occurs when, the positioning being declared available, the actual positioning error exceeds the AL without annunciating an alert within the required TTA. Misleading Information occurs when, the positioning system being declared available, the actual positioning error exceeds the PL. Typically, positioning systems are designed to tolerate some level of MI, provided the system can continue to operate safely within the AL. To properly monitor for integrity in the positioning system, both the fault and fault-free conditions which potentially lead to MI or HMI need to be characterized for the network and the UE.

Figure 9.1.1.4-A illustrates the concept of MI and HMI with respect to the KPIs, PL and PE.

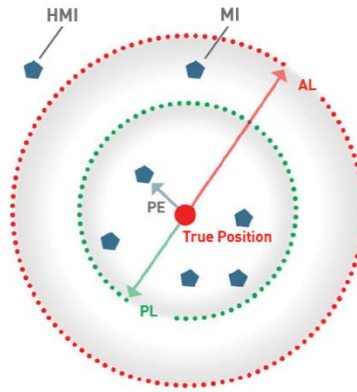


Figure 9.1.1.4-A: Relationship between Positioning Error (PE), Protection Level (PL), Alert Limit (AL), MI and HMI [32].

A useful representation for interpreting the relationship between the positioning integrity KPIs and PL is the so-called Stanford Diagram [33] in Figure 9.1.1.4-B. It should be noted that the Positioning Error (PE) in this diagram is the difference between the true position and the estimated position, computed by the positioning device. In practice, the true position is not known.

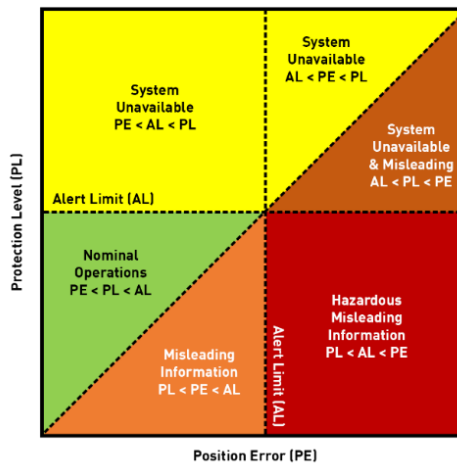


Figure 9.1.1.4-B: Stanford Diagram for integrity events, adapted from [33][34].

Important observations can be made from Figure 9.1.1.4-B in the context of this study:

1. The conditions represented above the diagonal line (Nominal Operations, System Unavailable) mean the positioning system is operating as intended by correctly detecting when the system should or should not be available.
2. The conditions represented below the diagonal line mean the system is not operating as intended. These conditions are what the positioning integrity system is designed to protect against, i.e., by monitoring the necessary fault and fault-free events to protect against MI or HMI for a given TIR. This concept is further described:
 - The TIR is equivalent to the probability per unit time of HMI, corresponding to the red block in the Stanford Diagram. The rate of MI (corresponding to the orange region), while undesirable, does not contribute towards the TIR.

In practice, positioning integrity systems are designed to tolerate some level of MI or HMI for a period of time within the TTA, without exceeding the TIR. This framework underpins the PL definition in this study (Section 9.1.1.3) and is particularly important for systems with communication latency, such as 3GPP NR, given assistance data can be monitored and sent by the network (i.e., the basis of this study). Sufficient time is therefore needed to signal that a fault is present. There is nothing prohibiting the TTA being set to zero for instantaneous detection, however a grace period must be accommodated to allow some level of functionality to be offloaded to the network when the network is utilized. Hence, the TTA depends on the overall positioning integrity system design (including 3GPP and non-3GPP elements) and is specified by the positioning system owner (e.g., a vehicle manufacturer) alongside the TIR and AL.

3. Interpretations when the system is **available** ($PL < AL$):

- **Nominal Operations ($PE < PL$):** the solution is available and operating safely without an integrity event.
- **Misleading Information ($PE > PL$ & $PE < AL$):** the solution is available but contains an MI integrity event due to $PE > PL$. It is still operating safely given PE does not exceed the AL.
- **Hazardous Misleading Information ($PE > PL$ & $PE > AL$):** the solution is available but contains an HMI integrity event due to $PE > AL$. It is still declared safe ($PL < AL$) when it should not have been.

4. Interpretations when the system is **unavailable** ($PL > AL$):

- **System Unavailable, False Alert ($PE < PL$ & $PE < AL$):** the solution is unavailable but is a false alert integrity event, given $PE < AL$.
- **System Unavailable ($PE < PL$ & $PE > AL$):** the solution is unavailable and operating as intended without an integrity event given $PE > AL$ was properly detected.
- **System Unavailable and Misleading ($PE > PL$ & $PE > AL$):** the solution is unavailable and contains a MI ($PE > PL$) integrity event.

9.2 Use Cases

RAT-Independent GNSS positioning integrity monitoring has a long operational history in the field of civil aviation [38][39][40][41][46]. The positioning integrity framework examined in this study extends beyond aviation, to address a broader suite of use case and architectural considerations for the 3GPP system. These concepts are further illustrated by the use case descriptions and KPIs provided below, including a particular focus on safety-critical and liability-critical applications, requiring the capability to validate the estimated position with greater trust.

9.2.1 Automotive

9.2.1.1 Road-Level Identification and Road-User Charging

Positioning integrity is a key input to determining whether a road vehicle is traveling on a highway or a neighbouring access road (e.g., a collector-distributor lane). For example, consider a manufacturer wanting to ensure their Advanced Driver-Assistance Systems (ADAS) only activates when the vehicle is on a highway. This requires the UE to determine with a high degree of positioning integrity which road the vehicle is traveling on, in order to avoid the potential for unintended ADAS functionality on the access road (or conversely to ensure the appropriate functionality has been activated on the highway). The road vehicle may also be subject to road-user charging with fees that vary depending which road is used, also requiring positioning integrity validation.

Consider an access road that is within 3 metres of a freeway, with a corresponding AL of 3 metres and TIR of $1 \times 10^{-7}/\text{hr}$ specified by the vehicle manufacturer. The road vehicle connects to a positioning integrity service provider via the mobile network to request UE-Based positioning integrity assistance data. The assistance data is applied by the UE alongside its local positioning measurements in order to compute the real-time PL. So long as the PL remains below the AL, the positioning system is available and functioning as intended, and the road-level identification can be made safely. If the PL exceeds the AL, the impacted positioning system should be declared unavailable on the vehicle and a road-level determination is not possible. For example, a network-detected fault can be flagged in the positioning integrity assistance data, resulting in a larger PL computed by the UE.

Another important positioning integrity aspect to take into account in road-user charging and other applications (like pay how you drive insurances) is that, because of their intrinsic nature, they have to be robust against attempts to deceive the positioning system. In these types of applications, the driver of the vehicle may be motivated to alter the position of its own vehicle in order to avoid being charged. Hence, the positioning integrity of the vehicle position needs to be ensured by being able to detect these deception attempts, for example by employing anti-tamper equipment and by cross-checking different positioning sources.

9.2.1.2 Lane-Level Identification

The same concepts and methods from 9.2.1.1 also apply to validating the lane in which the vehicle is traveling. Lane change warnings and manoeuvres are a crucial input to enabling various Levels of autonomy [42] which are illustrated in the 5GAA use case requirements [37], such as an AL of 1.5m and TIR of $1 \times 10^{-7}/\text{hr}$ or lower.

The ability to handle faults almost instantaneously on a road vehicle is absolutely critical in order to recover the situation and avoid a potential collision between lanes. The UE is responsible for monitoring localized events which need to be detected in the shortest time possible, i.e., ‘highly dynamic’ feared events (e.g., multipath, cycle slips and satellite feared events in the case of GNSS). The network is therefore used to monitor the low dynamic threats, which are less time-critical but still depend on a reliable communication channel with the UE. In the automotive and other 5G positioning use cases, the TTA is also far more stringent (e.g., 100ms in some cases) compared with an aviation TTA of 6 seconds (or slower) for precision approaches. Hence, the low latency of the 3GPP communications presents a strong synergy for supplying positioning integrity assistance data that is secure and assured.

Once again, the positioning system should remain available unless the PL exceeds the AL, in which case the system should be unavailable and the corresponding ADAS functionality on the vehicle disengaged. To avoid an integrity event, any feared event with an occurrence probability higher than the TIR (i.e., $>1 \times 10^{-7}/\text{hr}$) needs to be detected and mitigated within the TTA². The UE application is typically responsible for issuing alerts to inform the preventative or remedial actions required by the positioning system.

If a feared event occurs at the network or UE, the positioning system should be capable of determining its effect on the PL relative to the AL, within the required TTA, such that the position reported by the UE remains fault-free (i.e., even if the fault-free position leads to the system being unavailable). The TTA therefore represents the ability of the system to recover before being impacted by a potential integrity event. For some use cases, the TTA may simply be set to zero depending on the implementation requirements.

9.2.2 Rail

9.2.2.1 Safety-Critical Applications

Automatic Train Protection (ATP) applications are used to ensure that trains run safely and efficiently on the right tracks with appropriate speed. Automatic Train Protection aims to prevent a train proceeding beyond the point of danger and to prevent the speed of the train exceeding the permissible limit in the event of a driver error. It consists of the safe determination of position, speed and direction of train movement in order to supervise the safe movement of the train up to its stopping point. This application requires the combination of several functions (or lower level applications) which in turn are strongly dependent of the accurate and safe determination of position and speed of the trains. There are many ATP applications where positioning integrity could be employed, among them one can include Enhanced Odometry, Absolute Positioning, Cold Movement Detection, Train integrity and train length monitoring, Track Identification, Odometer Calibration, and Level Crossing Protection.

Emergency Management applications, like the trackside personnel protection (to protect personnel working on or close to the track from the trains using the network) and the door control supervision (to enable the opening of specific doors at particular stations), are also safety-critical applications where positioning integrity will improve the performances and reduce risks.

9.2.2.1 Liability-Critical Applications

Asset Management. The accuracy and confidence on the position needed for the location of the assets in some cases can be demanding and require high precision and reliable surveying. Fixed asset management applications are linked with the railway environment, from the infrastructure surveying and structural monitoring to the trackside equipment. Rolling stock asset management applications are in charge of the vehicles that move on a railway including both

² NOTE: If the lane-level requirement was simply specified by the accuracy estimate (e.g., $<1.5\text{m}$ at the 95th percentile), 5% of the estimated positions may still be impacted by feared events which far exceeds the required AL, potentially leading to an integrity event. Positioning integrity KPIs are instead used to define probabilities of failure over a given period of time rather than relying on the combined statistical distribution of the estimated positions (which are potentially contaminated by fault and fault-free events that go undetected). The positioning integrity methodologies allow an positioning integrity risk to be allocated based on the probability of occurrence for each feared event, and then quantified as a contribution to the total TIR. This ensures only the integrity-validated positions are included in the positioning estimate, meaning the nominal accuracy should be easily achieved.

powered and unpowered vehicles, for example locomotives, railroad cars, coaches, and wagons. Rolling stock applications include: fleet management, cargo monitoring, infrastructure charging, energy charging and hazardous cargo monitoring.

Protection and Emergency Management Systems. This group includes applications such as trackside personnel protection, management of emergencies and train warning systems. Management of emergencies can be greatly improved if an accurate, reliable and continuous location of the train is available, allowing the emergency teams to optimise their operations. Train warning systems are employed when some railways require a special warning to passengers on a platform when a train is approaching and is expected to pass the platform at a speed greater than a defined level. This application requires reliable details of train location, speed and other infrastructure data, and may result in an automatic station announcement via a public service broadcast.

Traffic Management and Information Systems. This group of applications includes traffic management systems (dispatching), but also on-board train monitoring and recording units, hazardous cargo monitoring and infrastructure charging.

9.2.3 Industrial IoT

In contrast to consumer-oriented Internet of Things (IoT), Industrial IoT (IIoT) use cases predominantly focus on operational, safety, and financially beneficial applications of the IoT ecosystem for businesses, infrastructure, and various industries. IIoT positioning integrity/reliability requirements are essential given various safety, payment, and regulatory critical applications. There are many outdoor IIoT devices/UEs employing GNSS-based positioning in various industries that include, but not limited to: Construction, Agriculture/forestry/fishing (smart farming), Oil/Gas industries, and Smart cities (traffic, electric and water systems, waste management, public safety, schools) derived from [30][45]. The ACIA white paper [47] provides some use cases and requirements on 5G positioning in general. An illustrative example relating to Automated Guided Vehicles (AGV) is provided below.

9.2.3.1 Path and Zone Identification for AGV

Positioning integrity is a key input to determining whether an AGV such as a forklift, in a factory or an open space such as ports or construction buildings, is traveling on the narrow halls within lots of different machinery. Aside from the demanding positioning accuracy, the trust needs to be assigned for the path and the zone of its movements. AGV not running into anything unexpectedly is something that needs to be assured. This requires that the AGV, which is the UE in this use-case, to determine with a high degree of positioning integrity which path it can travel within its defined work task. One can also consider that an industrial scenario can have several different zones in which different levels of positioning integrity can be defined, and hence depending on demand of the works in each zone the positioning methods and positioning integrity KPIs can be defined in respect to those. Once again, the positioning system should remain available unless the PL exceeds the AL, in which case the system should be unavailable and the corresponding AGV functionality on the vehicle is disengaged. The set AL for such use-case depends on how large and how densely equipped the factory is, and hence it is reasonable to assume that it can be set to some value between 0.5m to 3m depending on the controlled area use-case and demands. Further illustration of AGV, which requires support for positioning for tracking, routing and guiding is provided in [47].

9.2.4 Use Case Summary

Table 9.2.4 is adapted from [35][36] and supplemented by [34][37]. It summarises the typical KPI ranges to be expected on implementation for the Automotive and Rail categories. Importantly, the KPIs are illustrative only; KPIs are typically specified by the positioning system provider on implementation (e.g., a vehicle OEM), taking into consideration the 3GPP and non-3GPP components of the system.

Table 9.2.4: KPI examples for the Automotive, Rail and IIoT use cases [34][35][36][37].

NOTE: KPIs are defined by the service provider implementation.

AUTOMOTIVE EXAMPLES				
APPLICATION CATEGORIES	TIR	AL	TTA	Integrity Availability

Safety-Critical Applications <ul style="list-style-type: none">• Warnings (red light, obstacle, queue, curve speed, blind spot lane change, pedestrians etc)• Automated Driving (lane-level or better)• Emergency Brake Assist• Forward Collision Avoidance	Typical range: ≥10 ⁻⁸ /hr to ≤10 ⁻⁶ /hr	Typical range: ≥1.5m to <5m	Typically ranges from 100s of milliseconds to <10 seconds	Typically ranges from 95% to 99.9% or greater
Payment Critical Applications <ul style="list-style-type: none">• Road User Charging (RUC)• Pay Per Use Insurance• Taxi Meter• Parking Fee Calculation	Typical range: ≥10 ⁻⁶ /hr to ≤10 ⁻⁴ /hr	Typical range: ≥1.5m to <25m		Typically ranges from 95% to 99.9% or greater
Smart Mobility <ul style="list-style-type: none">• Freight and Fleet Management• Cargo/Asset Management• Vehicle Access/Clearance• Emergency Vehicle Priority• Speed Limit Information• In-Vehicle Signage• Reduce Speed Warning• Dynamic Ride Sharing				
RAIL EXAMPLES				
APPLICATION CATEGORIES	TIR	AL	TTA	Integrity Availability
Safety-Critical Applications <ul style="list-style-type: none">• Absolute Positioning• Train Awakening• Cold Movement Detector• Track Identification• Level Crossing Protection• Train Integrity and Train Length Monitoring	Typical range: ≥10 ⁻⁹ /hr to ≤10 ⁻⁸ /hr	Typical range: ≥2.5m to <25m	Typically <7s	Typically ranges from 95% to 99.9% or greater
Liability-Critical Applications <ul style="list-style-type: none">• Trackside Personal Protection• Management of Emergencies• Train Warning Systems• Infrastructure Charging• Hazardous Cargo Monitoring• On-Board Train Monitoring and Recording Unit• Traffic Management Systems	TBD	Typical range: ≥25m to <62.5m	Typically ranges from seconds to <30s	Typically ranges from 95% to 99.9% or greater
IIOT EXAMPLES				
APPLICATION CATEGORIES	TIR	AL	TTA	Integrity Availability
AGV Applications <ul style="list-style-type: none">• Mobile device tracking• Asset tracking• Process automation• Inbound logistics	Typical range: ≥10 ⁻⁸ /hr to ≤10 ⁻¹ /hr	Typical range: ≥0.5m to <30m (vertical/horizontal)	Typically ranges from 100s of milliseconds to <10 seconds	Typically ranges from 95% to 99.9% or greater

9.3 Positioning Integrity Error Categories

9.3.1 RAT-Independent

9.3.1.1 A-GNSS Feared Events

This section describes the types of feared events to be considered for implementing positioning integrity using A-GNSS. The feared events are further addressed as part of the UE-based and UE-assisted positioning integrity mode considerations in Section 9.4, including the summary of feared events in Table 9.4.1.1.

9.3.1.1.1 Feared events in the GNSS Assistance Data

a) Incorrect computation of the GNSS Assistance Data

GNSS correction networks collect and process GNSS measurements in order to estimate various GNSS corrections (e.g., the satellite orbits, clocks, etc.). If the corrections contain incorrect data, this can lead to incorrect computation of the PL and a potential integrity event. All impacted GNSS assistance data are described in section 8.1 of TS 38.305.

Different types of events can lead to the incorrect computation of corrections: there can be errors on the implementation of the algorithms employed by the GNSS corrections provider to compute the GNSS assistance data; equipment malfunction may corrupt the measurements employed by the GNSS corrections provider; or the correction data computed by the corrections provider may be corrupted before being sent. In any case these events are handled by the GNSS corrections provider by performing consistency checks on the input data, checking the validity of the corrections before sending them and applying CRCs.

b) External feared event impacting the GNSS Assistance Data

The GNSS corrections provider generates the correction data employed to estimate the location of the UE. Any event affecting the quality of the generated data will be considered a feared event impacting the GNSS corrections provider.

This is different than the incorrect computation of the GNSS assistance data, which is mainly due to wrong implementation of algorithms or corrupted data. These external events comprise situations affecting the estimation process that happens at the GNSS correction provider, such as erroneous data inputs used to compute the corrections (e.g. satellite, atmospheric or local environment feared events impacting the GNSS reference stations in the GNSS correction provider's network).

A first approach to handling these events is to monitor these types of situations at the GNSS corrections provider and, for those satellites not achieving some required threshold conditions, flag them or not send their corrections. This ON/OFF approach can work when there is only one level of target accuracy that needs to be achieved but, when there can be several levels of target accuracy and, moreover, when these levels are not predefined, then a more flexible and powerful approach is for the GNSS corrections provider to indicate the quality of each correction, thus allowing the location function to decide whether it uses the satellite or not and to have a better estimation of the location errors.

9.3.1.1.2 Feared events during positioning data transmission

a) Data integrity faults

Data tampering e.g., spoofing can also affect the quality and integrity of the positioning services provided by 5GS. For instance, the interface between 5GS and a GNSS Corrections Network (need for RTK, PPP-RTK, etc.) may be vulnerable to malicious attacks. The situation here is similar to the GNSS Data Channel tampering described in section 9.3.1.1.3 but applicable to another type of data transmission channel.

9.3.1.1.3 GNSS feared events

GNSS feared events are those which occur external to the UE and potentially impact the quality and availability of the GNSS signals.

a) Satellite feared events

Satellites can suffer HW failures and potentially output an incorrect signal for a period of time or permanently, depending on the magnitude of the issue. In situations like this the health of the GNSS satellite(s) and the signal(s) must be communicated to the UE in real-time. This is achieved by using flags in the message broadcast by SBAS systems [28][38] or directly by the affected GNSS constellation. Alternatively, the *GNSS-RealTimeIntegrity* IE can be used in UE-based mode. This is the most basic form of integrity capability included in LPP protocol.

b) Atmospheric feared events

The Ionosphere is the region of the atmosphere between around 80km – 600km above the Earth. The GNSS signals are delayed in the region above an altitude of 80km by an amount proportional to the number of free electrons given off by the sun. Since the ionospheric delay is frequency dependent, it can virtually be eliminated by making and differencing ranging measurements on two GNSS frequency bands e.g., B1-C/E1/L1 (1,575.42 MHz) and B2a/E5a/L5 (1,176.45 MHz). Although ionospheric delay errors are removed, this approach has the drawback that measurement errors are significantly magnified through the combination. When not removed, ionosphere represents the largest error source.

The troposphere is the lower part of the atmosphere that is nondispersive for frequencies up to 15 GHz. Within this medium, the phase and group velocities associated with the GNSS carrier and signal information (ranging code and navigation data) on the GNSS L-band frequencies are equally delayed with respect to free-space propagation. This delay is a function of the tropospheric refractive index, which is dependent on the local temperature, pressure, and relative humidity. Left uncompensated, the range equivalent of this delay can vary from about 2.4m for a satellite at the zenith and the user at sea level to about 25m for a satellite at an elevation angle of approximately 5° [48]. Basic models can correct up to 90%, linked to the dry component, while the remaining errors are linked to the wet component which is more difficult to predict due to uncertainties in the atmospheric distribution.

LPP already includes an IE for these correction data, namely *GNSS-SSR-STECCorrection*, *GNSS-SSR-GriddedCorrection*. The existing atmospheric messages in LPP remove a large portion of the atmospheric errors impacting the positioning accuracy. However, the residual errors after the atmospheric corrections have been applied may still have a magnitude sufficient to cause the position error to exceed the AL with a probability of occurrence greater than the TIR. In addition, if the temporal or spatial rate of change of these errors is unusually large, this may also lead to larger than anticipated residual errors. Additional integrity indicators are therefore necessary to detect these feared events. A key benefit of network-assisted integrity is to leverage the additional number of measurements, redundancy and cross-checks made available from a network of GNSS reference stations, potentially leading to lower TIRs and less overhead at the UE. Individual ionospheric and tropospheric quality indicators are missing and can be easily added as a field to each of these IEs.

c) Local Environment feared events

Multipath

Multipath is one of the most significant errors incurred in the GNSS receiver measurement process. The magnitude of multipath errors varies rapidly and significantly depending on the environment in which the receiver is located, satellite elevation angle, receiver signal processing, antenna gain pattern, and signal characteristics. Unlike the other error sources considered thus far, multipath errors are uncorrelated even in short-baselines and cannot be removed by differential techniques (e.g., RTK).

There are two multipath scenarios:

- Multipath without blockage (Line-of-Sight, LOS)

In addition to the direct satellite-to-receiver path, the signals are also reflected from the ground and other objects. These cause multiple copies of the signal or a broadening of the signal arrival time, both of which reduce precision. Since the path travelled by a multipath is always longer than the direct path, multipath arrivals are delayed relative to the direct path. Multipath reflections distort the correlation function between the received composite (direct path plus multipaths) signal and the locally generated reference in the GNSS receiver, and also distort the phase of the composite received signal, introducing errors in pseudorange and carrier phase measurements that are different among the signals from different satellites, and thus produce errors in position, velocity, and time [48].

- Multipath with blockage or shadowing (Non-Line of sight, NLoS)

The effects of multipath are commonly assessed when the direct path signal is received without attenuation, so that multipath power is lower than direct path power. When blockage or shadowing of the direct path occurs along with multipath, the direct path is attenuated and received power of the multipath may be even greater than the received power of the shadowed direct path. Such a phenomenon can occur in outdoor situations and also in indoor situations, when the direct path is significantly attenuated while passing through walls or ceiling and roof, while the multipath is reflected from another building and arrives with little attenuation through a window or other opening. Consequently, shadowing of the direct path and multipath has combined effects on the relative amplitudes of direct path and multipaths. In some cases, shadowing of the direct path may be so severe that the receiver only tracks the Non Line-of-Sight (NLoS) multipath(s) and errors of several tens of meters can appear in the pseudorange measurements.

NLoS is more likely to happen in urban environments and is an important issue for integrity. This is a local error, specific to each receiver and its mitigation takes place at the UE without assistance data from LMF.

Interference

The theoretical principle behind this threat is the jamming of data transmission in general between a transmitter and a receiver. The practical principle defines however the exclusive jamming of the GNSS receiver where the transmitted signal is weakest and most open to attack.

There are two forms of GNSS Radio Frequency Interference (RFI), Intentional and Unintentional:

- Unintentional RFI is due to a nearby radio device broadcasting at a frequency which impacts the GNSS signals.
- Intentional RFI is the deliberate action of blocking the reception of GNSS signals by broadcasting a strong signal on GNSS frequencies.

A typical jammer relies on power and spectral occupation to deny the GNSS signals. Studies of simple jamming attacks have demonstrated that it is relatively easy, given sufficient broadcast power, to deny the use of GNSS to many receivers in a given geographic area. Jamming represents complete disruption of GNSS signals by another radio frequency source, be it the sun, privacy seeking citizens, or belligerent nations. Jamming can have very serious impacts, depending upon the number and type of affected users, duration of the disruption, etc.

Simple jamming is a very easy attack to launch but is also very easily detected, readily localized, and often relatively easily mitigated. GNSS system providers offer protection against jamming by using stronger signals, broadcast on more frequencies, and using more constellations simultaneously.

Spoofing

In this type of threat the attacker threatens integrity and confidentiality of a GNSS transmission by broadcasting false signals with the intent that the victim receiver will misinterpret them as authentic signals. Spoofing aims at making the receiver compute a false position and time. Spoofing attacks are difficult to detect and can also be deployed in a coherent manner, as such bypassing any integrity detection and recovery measures (i.e. RAIM). Therefore, when such events occur, the measurements from the receiver can pass the integrity check, even if the error of the computed position far exceeds the expected accuracy.

GNSS system (e.g. GPS, Galileo etc) are working on securing their publicly broadcast signals. In order to overcome these threats, signal and message/data channel authentication solutions are being deployed by GNSS systems providers to ensure authenticity to the ranging measurements and data channels [43][44]. Such authentication solutions are especially useful for road users, UAVs, rail users, and timing users. These UEs will then need to retrieve the following information:

- Ranging Authentication Data: primarily the cryptographic data needed to verify the signal/ranging authentication;
- Data Channel Authentication data: the navigation data and their signatures.

The introduction of A-GNSS has partly solved the need for GNSS Data Authentication for UEs which can retrieve the GNSS Navigation Message from 5GS through an LPP transaction instead of the GNSS signals. On the other hand, ranging authentication continues to be a serious challenge. The idea is to protect the GNSS pseudorange, performed by the UE, from intentional acts, ensuring the trustworthiness of location and time.

RAT-dependent positioning techniques could be used as independent means to cross-check the authenticity of the position reported by the GNSS receiver, while *GNSS-ReferenceTime*, *GNSS-SystemTime*, and *NetworkTime IEs* could be used as redundant information to cross-check the authenticity of the GNSS time reported by the receiver. Besides

these capabilities, useful in detecting a spoofing event, 5GS could also enable GNSS ranging and navigation authentication by acting as an alternative data channel to the GNSS signal in space for the dissemination of cryptographic assistance data. In this scenario the UE could instantaneously verify that the received signal and data came from the correct source i.e., a GNSS constellation and avoid spending energy to retrieve the data from the GNSS signal.

9.3.1.1.4 UE feared events

UE specific errors are not possible to mitigate with assistance data from the network, the UE is responsible for mitigating these feared events locally, based on implementation.

a) GNSS receiver measurement error

Measurement errors are also induced by the receiver tracking loops, so this is an inherent noise within the receiver which causes jitter in the signal. Typical values for the noise and resolution error in the case of modern GNSS receivers are on the order of a decimetre or less in nominal conditions (i.e., without external interference) and negligible compared to errors induced by multipath.

b) Hardware faults

c) Software faults

9.3.1.1.5 LMF Feared Events

a) Hardware Faults

b) Software Faults

9.4 Positioning Integrity Methods

9.4.1 RAT-Independent

The scope of this study is limited to examining positioning integrity considerations for A-GNSS positioning.

9.4.1.1 A-GNSS Positioning Integrity Methods

The 3GPP specifications can be extended to support the determination of positioning integrity, by defining information elements and signalling procedures to transport assistance information to mitigate feared events. A summary of the feared events studied in Section 9.3 is provided in Table 9.4.1.1 below, including examples of the types of assistance information to be considered for inclusion in LPP

Table 9.4.1.1: Summary of A-GNSS feared events and integrity assistance information considerations (FFS).

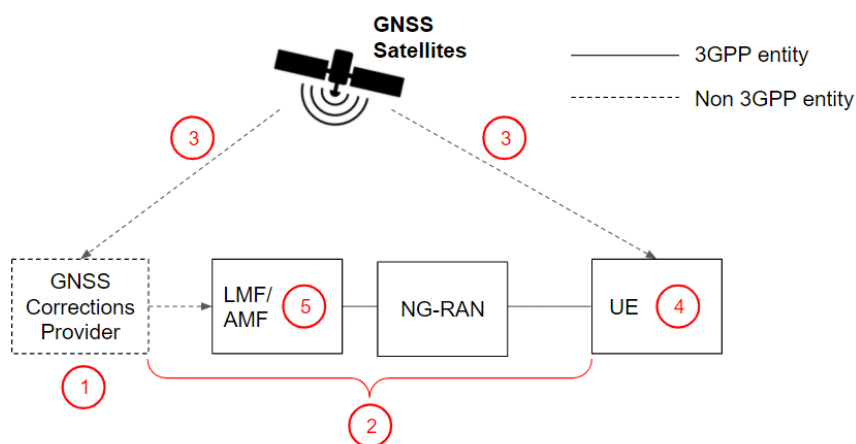
NOTE: The positioning integrity assistance information IEs are FFS as part of the WI.

*NOTE: The UE or LMF are responsible for mitigating these feared events locally, outside the scope of the specifications.

Feared Event Category	Feared Event	Examples of positioning integrity assistance information (FFS)
1. Feared events in the GNSS Assistance Data	Incorrect computation of the GNSS Assistance Data, e.g. software bug, corrupt or lost data	Validity or quality flags for existing assistance information

	External feared event impacting the GNSS Assistance Data, e.g. satellite, atmospheric or local environment feared events (Category 3) impacting the GNSS reference stations in the GNSS correction provider's network.	
2. Feared events during positioning data transmission	Data integrity faults	Data corruption check, e.g. CRC Data Authentication / Signature
3. GNSS feared events	Satellite feared events e.g. bad signal-in-space or bad broadcast navigation data	Satellite health or quality flags
	Atmospheric feared events	Ionospheric indicator Tropospheric indicator
	Local Environment feared events, e.g. Multipath, Spoofing, Interference	Assistance information: Trustable time reference, Data Authentication / Signature, Regionalized indicator of multipath, interference, jamming, spoofing, etc
4. UE feared events	GNSS receiver measurement error	e.g., <i>GNSS-MeasurementList</i>
	Hardware faults	*
	Software faults	*
5. LMF feared events	Hardware faults	*
	Software faults	*

Figure 9.4.1.1: Simplified relationship between the positioning integrity feared event categories and the 3GPP positioning architecture. Refer to [27] for a detailed description of the UE positioning architecture.



9.4.1.1.1 Signalling considerations

The following LPP signalling was identified in the study, for consideration in the WI:

- Signalling to determine the positioning integrity capability
- Signalling to deliver the KPIs and integrity results
- Signalling to deliver the integrity assistance information to the UE
- Signalling to deliver the integrity information related to the GNSS positioning measurements from the UE to the LMF

Table 9.4.1.1.1 summarizes the UE-based and UE-assisted considerations for supporting positioning integrity in the 3GPP specifications, with respect to the feared events identified in Table 9.4.1.1 and the signalling considerations above.

Two modes of integrity result reporting are also identified below for consideration in the WI:

- **Mode 1 of Integrity Result Reporting : PL Reporting**

The integrity computing entity calculates the PL, based on the measurement, assistance information and TIR. Then, the calculated PL is directly reported to where the LCS client resides (Network or UE). Hence, the integrity computing entity does not judge whether the positioning system is still available, it simply provides whatever PL value it has obtained. It is left to the LCS client itself to determine if the positioning system is still available based on the reported PL.

- **Mode 2 of Integrity Result Reporting : Integrity Event Flagging**

The integrity computing entity calculates the PL, based on the measurement, assistance information and TIR. Then, the integrity computing entity further compares the calculated PL with the given AL to determine if the positioning system is still available to offer trustable position estimation. Thus, the integrity computing entity may only have to report a binary flag (0 and 1) to indicate whether the positioning system is available or not. Thus, in this case the LCS client can be directly informed about the system availability, without conducting further evaluation by itself.

Table 9.4.1.1.1: Summary of network-assisted (UE-Based) and UE-assisted (LMF-Based) positioning integrity mode considerations.

NOTE: The table provides a summary of considerations and the final details and specification impacts are FFS in the WI.

*NOTE: Examples of KPIs are the TIR, AL, TTA. Examples of Integrity results are the PL and Integrity Availability.

**NOTE: From LMF to UE does not mean the integrity assistance information is generated by the LMF.

Positioning Integrity Mode	Location service type	Source of KPIs*	Source of Integrity results*	Positioning Integrity assistance information**	Specification impact
Network assisted (UE-based): Positioning integrity result is derived by the UE	MO-LR	UE internal implementation	UE internal implementation	From LMF to UE: - Feared events in the GNSS Assistance Data - Feared events in transmitting the data to the UE - GNSS feared events	Procedure to transfer Integrity assistance information from LMF to UE
	MT-LR	From LMF	From UE	From LMF to UE: - Feared events in the GNSS Assistance Data - Feared events in transmitting the data to the UE - GNSS feared events	Procedure to transfer Integrity assistance information and KPIs from LMF to UE Procedure to transfer Integrity results from UE to LMF
UE assisted (LMF-based): Positioning integrity result is derived by the LMF	MO-LR	From UE	From LMF	From GNSS corrections provider (external source) to LMF: - Feared events in the GNSS Assistance Data - Feared events in transmitting the data to the UE - GNSS feared events From UE to LMF:	Procedure to transfer Integrity assistance information and KPIs from UE to LMF Procedure to transfer Integrity results from LMF to UE

				- UE feared events - GNSS feared events	
	MT-LR	LMF implementation	LMF internal implementation	From GNSS corrections provider (external source) to LMF: - Feared events in the GNSS Assistance Data - Feared events in transmitting the data to the UE - GNSS feared events From UE to LMF: - UE feared events - GNSS feared events	Procedure to transfer Integrity assistance information from UE to LMF

9.4.1.1.2 Summary of A-GNSS Positioning Integrity Methods

The detection of feared events is necessary to support the implementation of positioning integrity. Assistance information and associated IEs can be optionally sent between the LMF and the UE to mitigate the feared events. LPP signalling considerations for UE-based and UE-assisted positioning integrity have been examined in this section to support the use cases in Section 9.2. To ensure that the system meets the integrity goals and requirements, it must be systematically validated, possibly including compliance to relevant industry functional safety specifications such as ISO-26262 for automotive. Integrity validation is considered outside the scope of the 3GPP specifications as it concerns a specific integrity system implementation.

The following considerations are also noted from the study contributions:

In [49], it is stated that the integrity level can be either a target, an estimated achievable, predicted or an already achieved integrity level. An integrity level classification (in an example) can consist of four different levels, of high, medium, low and no integrity support for both UE and the network. The integrity level can be determined based on a wide range of parameters such as QoS, different detected error sources, speed of the UE, weather condition, mobility behaviour of the UE, coverage and capacity condition of the network.

In [31][50], it is pointed out that RTCM (Radio Technical Commission for Maritime Services) SC-134 is working on the integrity message definition now. The work has reached a planning and experimental stage following initial investigations on the application scenario requirements. Currently, four integrity message groups are foreseen - signal in space integrity, global integrity, network integrity, and local integrity – and the milestone for draft message definition and approvals are currently targeting a 2021/2022 timeframe [31]. Both [31] and [50] suggest that content from RTCM on this topic represents a potential resource for consideration within this study depending what content is available from SC-134 within the Release 17 timeframe.

In [51][52], the topics of jamming and spoofing of GNSS signals are discussed. It is noted that crowd sourced UE observations, from a given region, can be provided to the location server, which can provide crowd-sourced information to other UEs when entering the region.

In [53], the concept of uncertainty of the GNSS ranging measurement has been studied for both UE-based and UE-assisted positioning integrity. In this concept, quality indicators for each individual GNSS error source (satellite clock, orbit, etc.) and local errors (multipath, etc.) are aggregated into one quality parameter for the measurement performed by the UE to a specific satellite.

10 Identified NR impacts in Rel-17

10.1 NR positioning for UEs in RRC_INACTIVE state

NR positioning for UEs in RRC_INACTIVE state is recommended for normative work, including

- DL, UL and DL+UL positioning methods
- UE-based and UE-assisted positioning solutions
- Support of UE positioning measurements for UEs in RRC_inactive state
 - Options that can be considered include DL-PRS or DL-PRS and SSB
- Support of gNB positioning measurements for UEs in RRC_inactive state

The details of how to enable the UE positioning in RRC_INACTIVE state can be further discussed during normative work. These details may include, but are not limited to the following aspects:

- UL reference signals (e.g., SRS for positioning, PRACH preambles) for UL measurements
- Signalling and procedures for support the assistance data delivery, DL-PRS configuration, UL reference signals for positioning resource configuration, measurement reporting, which may be developed based on the enhancements of existing signalling and procedures (e.g., existing 2-step and/or 4-step PRACH procedures, paging procedure, small data transmission).

The following procedures are recommended for normative work for DL positioning methods in RRC_INACTIVE:

- Reporting of DL-PRS measurement and/or location estimate performed in RRC_INACTIVE when the UE is in RRC_INACTIVE.
- The reporting of DL-PRS measurement and/or location estimate performed in RRC_INACTIVE when the UE is in RRC_INACTIVE is enabled by enhancing small data transmission in RRC_INACTIVE. (Details of the use of SDT to be studied in the WI phase)

NOTE: The following procedures are considered to have already been supported and can be reused for DL positioning in RRC_INACTIVE

- On-demand SI request in RRC_INACTIVE for assistance data delivery by broadcast in RRC_INACTIVE
- *ProvideAssistanceData* in RRC_CONNECTED for DL-PRS configuration used in RRC_INACTIVE downlink positioning
- *RequestLocationInformation* can be sent in RRC_CONNECTED for DL-PRS measurement or location estimate performed in RRC_INACTIVE

10.2 On-demand transmission and reception of DL PRS

From a physical layer perspective, on-demand transmission and reception of DL PRS, which includes at least the following is recommended

- UE-initiated request of on-demand DL PRS transmission
- LMF (network)-initiated request of on-demand DL PRS transmission
- Above enhancements are recommended for both DL and DL+UL positioning methods and both UE-based and UE-assisted positioning solutions.

From upper layers perspective, on-demand DL PRS functionality is deemed beneficial primarily for below reasons:

Efficiency: On-demand DL-PRS avoids unnecessary overhead, waste of energy, etc. in the case that no UE positioning is required during a particular time or in a particular area of a network. In case of beamformed DL-PRS, DL-PRS transmission in all beam sweeping directions may result in an unnecessary transmission of DL-PRSs.

Latency: The current DL-PRS configuration may not be sufficient to meet the response time requirements of the LCS client; e.g., may have a too large periodicity.

Accuracy: The current DL-PRS configuration may not be sufficient to meet the accuracy requirements of the LCS client; e.g., may have a too small bandwidth, too few repetitions, etc.

It should be also noted that accuracy and latency are however tradeoffs of efficiency.

From Upper layers perspective the below conclusions have been made for on demand PRS functionality.

- UE-initiated request of on-demand DL-PRS transmission is recommended for normative work; the details will be decided during WI phase.
- LMF Initiated on-demand control of DL-PRS transmission is recommended for normative work; the details will be decided during WI phase.
- The exact parameters that can be dynamically changed and necessary measurement and/or assistance information for LMF/UE initiated on demand PRS are expected to be decided during WI phase.

10.3 Aggregation of DL PRS resources

Simultaneous transmission by the gNB and reception by the UE of intra-band one or more contiguous carriers in one or more contiguous PFLs can be studied further and if needed, specified during normative work

- From both gNB and UE perspective, the applicability and feasibility of this enhancement for different scenarios, configurations, bands and RF architectures, can be further studied

10.4 Aggregation of SRS for positioning resources

Simultaneous transmission by the UE and aggregated reception by the gNB of the SRS for positioning in multiple contiguous intra-band carriers can be studied further and if needed, specified during normative work.

- From both gNB and UE perspective, the applicability and feasibility of this enhancement for different scenarios, configurations, particular bands and RF architectures, can be further studied.

10.5 Enhancements for UE Rx/Tx and gNB Rx/Tx timing delays

The methods, measurements, signaling, and procedures for improving positioning accuracy in the presence of the UE Rx/Tx timing delays, and/or gNB Rx/Tx timing delays are recommended for normative work, including

- DL, UL and DL+UL positioning methods
- UE-based and UE-assisted positioning solutions
- Note: The details of the solutions are left for further discussion in normative work.

10.6 Enhancements for angle based methods

The enhancements of the procedure, measurements, reporting, and signalling for improving the accuracy of

- UL AoA is recommended for normative work for network-based positioning solutions.
- DL-AoD is recommended for normative work for UE-based and network-based (including UE-assisted) positioning solutions.

10.7 Enhancements of information reporting from UE and gNB for supporting multipath/NLOS mitigation

Enhancements of information reporting from UE and gNB for supporting multipath/NLOS mitigation can be studied further, and if needed, specified during normative work for improving positioning accuracy.

- Note: The details of the enhancements of reporting are left for further discussion in normative work, which may include, but are not limited to the following information associated with multi-path, e.g., LOS/NLOS identification,

time of arrival of the multi-path components, signal power and/or relative power, power delay profile, angle, and/or polarization information, coherence bandwidth, etc.

10.8 Enhancements of signaling & procedures for reducing NR positioning latency

Aperiodic reception of DL PRS from the TRPs of the serving gNB and aperiodic reception of DL PRS from the TRPs of the neighbouring gNBs can be studied further and if needed, specified during normative work.

- Note: Aperiodic reception corresponds to DCI-triggered reception

Semi-persistent reception of DL PRS from the TRPs of the serving gNB and Semi-persistent reception of DL PRS from the TRPs of the neighbouring gNBs can be studied further and if needed, specified during normative work.

- Note: Semi-persistent reception in the above corresponds to MAC-CE activated reception

The following enhancements of signaling & procedures for reducing NR positioning latency are recommended for normative work, including DL and DL+UL positioning methods

- The details of the solutions are left for further discussion in normative work, which may include the following aspects:
 - Latency reduction related to the measurement gap
 - Latency reduction related to the reporting and request of the measurement (e.g., via RRC signaling, MAC-CE and/or physical layer procedure, and/or priority rules)
 - Latency reduction related to measurements
 - Latency reduction related to the reporting and request of positioning assistance data (e.g., via location scheduling in advance of the time of when the location is needed) [RAN2]

The following enhancements of signaling & procedures for reducing NR positioning latency can be studied and specified, if needed

- Latency reduction related to the request and response of positioning assistance data (e.g., via RRC signaling, MAC-CE and/or physical layer procedure)
- Latency reduction related to the reception of DL PRS (e.g., priority rules for the reception of DL PRS)
- Latency reduction related to the reporting of the measurements (e.g., CG-based transmission) [RAN2]
- Latency reduction related to the request and response of UE positioning capabilities (e.g., via storing UE capabilities in the network) [RAN2].

No assumptions are made on whether the LCS architecture specified in TS 23.273 is enhanced or not.

10.9 DL positioning measurement in RRC_IDLE state

From a physical layer perspective, it is feasible for a UE to perform DL positioning measurement in RRC_IDLE state.

- Note: This does not imply that measurements have to be reported in RRC_IDLE state.

The following procedures are considered as feasible for DL positioning methods in RRC_IDLE:

- Reporting of DL-PRS measurement and/or location estimate performed in RRC_IDLE when the UE is in RRC_INACTIVE/RRC_CONNECTED.

NOTE: The following procedures are considered to have already been supported and can be reused for positioning in RRC_IDLE

- On-demand SI request in RRC_IDLE for assistance data delivery by broadcast in RRC_IDLE
- *ProvideAssistanceData* can be sent in RRC_CONNECTED for DL-PRS configuration used in RRC_IDLE downlink positioning

- *RequestLocationInformation* can be sent in RRC_CONNECTED for DL-PRS measurement and/or location estimate performed in RRC_IDLE

10.10 RAT-Independent positioning

RAT-Independent positioning in RRC_IDLE/INACTIVE is recommended for normative work. The exact procedures that can be supported for RAT-Independent positioning in RRC_IDLE/INACTIVE can be further studied.

10.11 Signalling and procedures to support GNSS positioning integrity

Signalling and procedures to support GNSS positioning integrity determination are recommended for normative work. The details of the solutions are left for further discussion in normative work, which may include the following aspects:

- The assistance information that will be used to support integrity determination;
- The information that will be used to provide the positioning integrity KPIs and integrity results.
- Support of integrity for UE-Based and UE-Assisted A-GNSS positioning.

11 Conclusions

This study focused on the analysis of potential enhancements and solutions necessary to support the high accuracy, low latency, high network efficiency and device efficiency to NR positioning targeting both general commercial and IIOT use cases.

In the study item, Rel-17 target positioning requirements for RAT dependent solutions were discussed and defined for general commercial use cases and IIoT use cases, including horizontal and vertical positioning accuracy, and physical layer and end-to-end positioning latency (see Clause 5). Additional scenarios and channel models for evaluating Rel-17 NR positioning enhancements were developed for the evaluation of the achievable positioning performance of the enhancements (see Clause 6).

The potential positioning enhancements for improving positioning accuracy, reducing latency, and improving network and device efficiency of NR positioning were studied. The potential positioning enhancements, which were investigated rigorously in this study, are outlined in Clause 7.

NR positioning accuracy with Rel.16 positioning solutions were evaluated under the condition that gNB time synchronization error and gNB/UE TX/RX timing errors are not modelled for InF-SH scenario and InF-DH scenario for both FR1 and FR2 bands. The evaluation results show:

- For horizontal positioning accuracy,
 - in the InF-SH scenario, based on the results provided by a majority of sources, sub-meter level @ 90% is achieved in both FR1 and FR2 bands.
 - in the InF-DH scenario, based on the results provided by a majority of sources, sub-meter level @ 90% is not achieved in both FR1 and FR2 bands.
- For vertical positioning accuracy
 - in the InF-SH scenario,
 - sub-meter level @ 90% is achieved by some sources but not achieved by some other sources in FR1 band
 - sub-meter level @ 90% is achieved by all sources in FR2 band;
 - in the InF-DH scenario,
 - sub-meter level @ 90% is achieved by some sources and is not achieved by some other sources in both FR1 and FR2 bands

For the case without modeling synchronization and gNB/UE TX/RX timing errors in the IOO scenario

- Based on the results provided by a majority of the sources, 1 m level @ 90% of horizontal positioning accuracy is achieved by Rel.16 in IOO scenario

For the case without modeling synchronization and gNB/UE TX/RX timing errors in the UMa scenario

- Based on the results provided, 10 m level @ 90% of horizontal positioning accuracy is achieved by Rel.16 in UMa scenario

For the case without modeling synchronization and gNB/UE TX/RX timing errors in the UMi scenario

- Based on the results provided by some of the companies, 1 m level @ 90% of horizontal positioning accuracy is achieved by Rel.16 in UMi scenario

The impact of NLOS/multipath on NR positioning accuracy and the resolutions for NLOS/multipath mitigation were investigated. NR positioning utilizing LOS/NLOS identification, outlier rejection, NLOS mitigation based on triangle inequality algorithms improve performance of positioning accuracy with respect to solutions that do not apply these techniques.

The impact of gNB/UE TX/RX timing errors on NR positioning accuracy were investigated. Evaluation results show the gNB/UE TX/RX timing errors have significant impact on positioning accuracy.

Aggregation of NR positioning frequency layers for improving positioning accuracy were investigated. Evaluation results show that aggregation of NR positioning frequency layers improves positioning accuracy under certain scenarios, configurations, and assumptions on modelled impairments as outlined in Clause 8.4.

Physical layer latency for Rel.16 DL-TDOA/DL-AOD UE-Assisted, UL-TDOA/UL-AOA, Multi-RTT, E-CID and DL-only UE-based NR positioning were investigated, and the major physical layer latency components for these NR positioning techniques were also identified as shown in Clause 8.4.

The UE efficiency (power saving) in the RRC_IDLE/RRC_INACTIVE states were also analysed, and power saving gains are observed with detailed observations related to power savings are outlined in Clause 8.4.

The network efficiency in terms of resource utilization was analyzed and benefits of potential positioning enhancements observed are outlined in Clause 8.4.

The potential positioning enhancements for improving positioning accuracy, reducing latency, and improving network and device efficiency of NR positioning were studied.

The following enhancements have been recommended for normative work

- NR positioning for UEs in RRC_INACTIVE state, including
 - DL, UL and DL+UL positioning methods
 - UE-based and UE-assisted positioning solutions
 - Support of UE positioning measurements for UEs in RRC_inactive state
 - Options that can be considered include DL-PRS or DL-PRS and SSB
 - Support of gNB positioning measurements for UEs in RRC_inactive state
- On-demand transmission and reception of DL PRS, which includes at least
 - UE-initiated request of on-demand DL PRS transmission
 - LMF (network)-initiated request of on-demand DL PRS transmission
 - Above enhancements are recommended for both DL and DL+UL positioning methods and both UE-based and UE-assisted positioning solutions.
- The methods, measurements, signaling, and procedures for improving positioning accuracy in the presence of the UE Rx/Tx timing delays, and/or gNB Rx/Tx timing delays, including
 - DL, UL and DL+UL positioning methods
 - UE-based and UE-assisted positioning solutions

- The enhancements of the procedure, measurements, reporting, and signalling for improving the accuracy of
 - UL AoA for network-based positioning solutions.
 - DL-AoD for UE-based and network-based (including UE-assisted) positioning solutions
- The enhancements of signalling & procedures for reducing NR positioning latency, including DL and DL+UL positioning methods. The details of the solutions are left for further discussion in normative work, which may include the following aspects:
 - the measurement gap
 - the measurement request and reporting (e.g., via RRC signalling, MAC-CE and/or physical layer procedure, and/or priority rules)
 - the measurement time

The following enhancements are considered beneficial for the purpose of improving positioning accuracy, reducing latency, improving network and/or device efficiency and are being recommended to be studied further and if needed, specified during normative work

- Simultaneous transmission by the gNB and aggregated reception by the UE of intra-band one or more contiguous carriers in one or more contiguous PFLs
- Simultaneous transmission by the UE and aggregated reception by the gNB of the SRS for positioning in multiple contiguous intra-band carriers
- Enhancements of information reporting from UE and gNB for supporting multipath/NLOS mitigation
- Aperiodic reception of DL PRS from the TRPs of the serving gNB and aperiodic reception of DL PRS from the TRPs of the neighbouring gNBs
- Semi-persistent reception of DL PRS from the TRPs of the serving gNB and Semi-persistent reception of DL PRS from the TRPs of the neighbouring gNBs
- Enhancements of signalling & procedures for reducing NR positioning latency related to
 - the request and response of positioning assistance data (e.g., via RRC signalling, MAC-CE and/or physical layer procedure)
 - the reception of DL PRS (e.g., priority rules for the reception of DL PRS)

From a physical layer perspective, it is feasible for a UE to perform DL positioning measurement in RRC_IDLE state. This does not imply that measurements have to be reported in RRC_IDLE state.

It is recommended to proceed with a normative work to support NR positioning enhancements.

Annex A:
Void

Annex B:

Appendix to summary of performance evaluations

B.1 Evaluation of horizontal positioning accuracy with gNB/UE TX/RX timing error

Table B.1-1: Summary of evaluated gNB/UE TX/RX timing error parameters and achieved horizontal positioning accuracy in InF-SH baseline scenario for Rel.16 positioning method.

Company name (Positioning method)	FR1 / FR2	gNB/UE TX/RX timing error mitigation is on/off	Evaluated UE TX/RX timing error values (Y value)	Evaluated gNB TX/RX timing error values (X value)	Is horizontal positioning accuracy 0.2m @ 90% met?	Is horizontal positioning accuracy 0.5m @ 90% met?
[10] (Multi-RTT)	FR1	Off at gNB Off at UE	10 ns	5 ns	NO	NO
	FR1	Ideal at gNB On at UE	0 ns	5 ns	NO	YES
[7] (DL-TDOA)	FR1	Off at gNB	0 ns	0.5 ns	NO	NO
	FR2	Off at gNB	0 ns	0.5 ns	NO	YES
[4] (DL/UL-TDOA)	FR1	Off at gNB	N/A	1.4ns (2ns inter- gNB difference)	NO	NO
[4] (UL-TDOA/AoA)	FR1	Off at gNB	N/A	1.4ns (2ns inter- gNB difference)	NO	YES
[4] (Multi-RTT)	FR1	Off at gNB Off at UE	5.6ns (8ns intra-UE Rx - Tx difference)	1.4ns (2ns intra- gNB Rx – Tx difference)	NO	NO
[4] (UL-TDOA)	FR1	On at gNB	N/A	0ns inter-gNB difference	YES	YES
				0.2ns inter- gNB difference	YES	YES
				0.5ns inter- gNB difference	NO	YES
				1ns inter-gNB difference	NO	NO
[5] (DL-TDOA)	FR1	Off at gNB Off at UE	0 ns	0 ns	YES	YES
			0.5ns	0.5ns	NO	YES
			1ns	0.5ns	NO	YES
			2ns	0.5ns	NO	YES
			3ns	0.5ns	NO	YES
			5ns	0.5ns	NO	YES
			0.5ns	1ns	NO	YES
			0.5ns	2ns	NO	NO
			0.5ns	3ns	NO	NO
			0.5ns	5ns	NO	NO
[5] (Multi-RTT)	FR1	Off at gNB Off at UE	0 ns	0 ns	YES	YES
			0.5ns	0.5ns	NO	YES
			1ns	0.5ns	NO	YES
			2ns	0.5ns	NO	YES
			3ns	0.5ns	NO	YES
			5ns	0.5ns	NO	YES
			0.5ns	1ns	NO	YES
			0.5ns	2ns	NO	YES
			0.5ns	3ns	NO	NO
			0.5ns	5ns	NO	NO
[17] (DL-TDOA)	FR2	Off at gNB Off at UE	0.0ns	0.0ns	YES	YES
			0.1ns	0.1ns	YES	YES
			0.2ns	0.2ns	YES	YES
			0.5ns	0.5ns	NO	YES
			1.0ns	1.0ns	NO	NO
[20] (DL-TDOA)	FR2	Off at gNB Off at UE	N/A	0ns	YES	YES
		Off at gNB Off at UE	N/A	1ns	NO	YES

		Off at gNB Off at UE	N/A	2ns	NO	NO
		Off at gNB Off at UE	N/A	4ns	NO	NO
		Off at gNB Off at UE	N/A	8ns	NO	NO
		On at gNB	N/A	0ns	YES	YES
		On at gNB	N/A	8ns	YES	YES

Table B.1-2: Summary of evaluated gNB/UE TX/RX timing error parameters and achieved horizontal accuracy in InF-DH baseline scenario for Rel.16 positioning methods.

Company name (Positioning method)	FR1 / FR2	gNB/UE TX/RX timing error mitigation is on/off	Evaluated UE TX/RX timing error values (Y value)	Evaluated gNB TX/RX timing error values (X value)	Is positioning accuracy 0.2m @ 90% met?	Is positioning accuracy 0.5m @ 90% met?
[10] (Multi-RTT)	FR1	Off at gNB Off at UE	10 ns	5 ns	NO	NO
	FR1	Ideal at gNB On at UE	0 ns	5 ns	NO	NO
[7] (DL-TDOA)	FR1	Off at gNB	0 ns	0.5 ns	NO	NO
	FR2	Off at gNB	0 ns	0.5 ns	NO	NO
[4] (DL/UL-TDOA)	FR1	Off at gNB	N/A	1.4ns (2ns inter-gNB difference)	NO	NO
[4] (UL-TDOA/AoA)	FR1	Off at gNB	N/A	1.4ns (2ns inter-gNB difference)	NO	NO
[4] (Multi-RTT)	FR1	Off at gNB Off at UE	5.6ns (8ns intra-UE Rx - Tx difference)	1.4ns (2ns intra-gNB Rx - Tx difference)	NO	NO
[5] (DL-TDOA)	FR1	Off at gNB Off at UE	0 ns	0ns	YES	YES
			0.5ns	0.5ns	NO	YES
			1ns	0.5ns	NO	YES
			2ns	0.5ns	NO	YES
			3ns	0.5ns	NO	YES
			5ns	0.5ns	NO	YES
			0.5ns	1ns	NO	YES
			0.5ns	2ns	NO	NO
			0.5ns	3ns	NO	NO
[5] (Multi-RTT)	FR1	Off at gNB Off at UE	0 ns	0ns	YES	YES
			0.5ns	0.5ns	NO	YES
			1ns	0.5ns	NO	YES
			2ns	0.5ns	NO	YES
			3ns	0.5ns	NO	YES
			5ns	0.5ns	NO	YES
			0.5ns	1ns	NO	YES
			0.5ns	2ns	NO	YES
			0.5ns	3ns	NO	NO
[17] (DL-TDOA)	FR2	Off at gNB Off at UE	0.0ns	0.0ns	YES	YES
			0.1ns	0.1ns	YES	YES
			0.2ns	0.2ns	YES	YES
			0.5ns	0.5ns	No	No
			1.0ns	1.0ns	No	No
			2.0ns	2.0ns	No	No

Table B.1-3: Summary of evaluated gNB/UE TX/RX timing error parameters and achieved horizontal positioning accuracy in IOO scenario for Rel.16 positioning method.

Company name (Positioning method)	FR1 / FR2	gNB/UE TX/RX timing error mitigation is on/off	Evaluated UE TX/RX timing error values (Y value)	Evaluated gNB TX/RX timing error values (X value)	Is horizontal positioning accuracy 0.2m @ 90% met?	Is horizontal positioning accuracy 0.5m @ 90% met?
[8] (DL-TDOA)	FR1	Off at gNB Off at UE	1.5 ns	0.5 ns	NO	NO
[8] (UL-TDOA)	FR1	Off at gNB Off at UE	1.5 ns	0.5 ns	NO	NO
[8] (Multi-RTT)	FR1	Off at gNB Off at UE	1.5 ns	0.5 ns	NO	NO
[8] (DL-TDOA)	FR2	Off at gNB Off at UE	1.5 ns	0.5 ns	NO	NO
[8] (UL-TDOA)	FR2	Off at gNB Off at UE	1.5 ns	0.5 ns	NO	NO
[8] (Multi-RTT)	FR2	Off at gNB Off at UE	1.5 ns	0.5 ns	NO	NO

Table B.1-4: Summary of evaluated gNB/UE TX/RX timing error parameters and achieved horizontal positioning accuracy in UMi scenario for Rel.16 positioning method.

Company name (Positioning method)	FR1 / FR2	gNB/UE TX/RX timing error mitigation is on/off	Evaluated UE TX/RX timing error values (Y value)	Evaluated gNB TX/RX timing error values (X value)	Is horizontal positioning accuracy 1m @ 90% met?
[17], UMi with $\Delta\tau$ (RTT)	FR1	Off at gNB Off at UE	1 ns	1 ns	No
[17], UMi with $\Delta\tau$ (RTT)	FR1	Off at gNB Off at UE	2 ns	2 ns	No
[17], UMi with $\Delta\tau$ (RTT)	FR1	Off at gNB Off at UE	5 ns	5 ns	No
[17], UMi with $\Delta\tau$ (RTT)	FR1	Off at gNB Off at UE	10 ns	10 ns	No
[17], UMi without $\Delta\tau$ (RTT)	FR1	Off at gNB Off at UE	2 ns	2 ns	Yes
[17], UMi without $\Delta\tau$ (RTT)	FR1	Off at gNB Off at UE	5 ns	5 ns	No
[17], UMi without $\Delta\tau$ (RTT)	FR1	Off at gNB Off at UE	10 ns	10 ns	No

B.2 Evaluation of physical layer latency

Table B.2-1: physical layer latency for Rel.16 DL-TDOA/DL-AOD UE-Assisted NR positioning

Source Reference to Tdoc #	Physical layer latency for DL-TDOA/DL-AOD, ms	Comments on major assumptions and physical layer latency components
[17]	[57-823]	Major Assumption: Connected state, FR1, (N,T) = (6,8) PRS capability Major components: Location Request reception, MG request & configuration, PRS/MG Alignment, PRS processing capabilities
[4]	FR1: 51.5-66ms (1 samp.) 111.5-126.5ms (4 samp. CSSF = 1) 171.5-186ms (4 samp. CSSF = 2)	Major assumptions: PRS periodicity is 20ms MG is requested Major components PRS measurement
[4]	FR1: 171.5-178.5ms (1 samp.) 651.5-658.5ms (4 samp. CSSF = 1)	Major assumptions: PRS periodicity is 160ms MG is not requested (sharing with existing RRM gap 6ms/40ms) Major components PRS measurement
[7]	FR1: 106.23 ms FR2: 667.87 ms	Major assumptions: RRC Connected; 4 samples; CSSF=1; Measurement Gap Repetition Period is 20ms. Major components: Measurement gap request procedures UE positioning measurement
[5]	FR1: [64-11556] FR2 : [728-328996]	Major assumptions and components: For FR1: DL measurement & process delay = $(LCM(T_{PRS}, T_{measGap})) \cup (T_{Process\ time})$, PRS and MG is periodicity The minimum value is 22ms for $LCM(T_{PRS}, T_{measGap}) = 20ms$, (N,T) = (6,8) The maximum value is 11514 ms for $LCM(T_{PRS}, T_{measGap}) = 10240ms$, (N,T) = (6,1280) For FR2: DL measurement & process delay = $(LCM(T_{PRS}, T_{measGap}) \times N_{RxBeam} \times N_{PosOccasion}) \cup (T_{Process\ time})$, $N_{RxBeam} = 8$, $N_{PosOccasion} = 4$ The minimum value is $20 \times 4 \times 8 + 2ms = 642ms$ The maximum value is $(10240 \times 8 \times 4 + 1280 \times 6) = 328954ms$ MG request and configuration Location Request and report
[11]	FR1: [38-235.6] FR2: [35-229.6]	Major Assumptions: Start and End States: RRC_CONNECTED, MG configuration enabled, MGRP = 20ms-160ms, 1 DL PRS occasion, T=8-160 ms DL PRS processing time. Major Components: Request Location reception and processing, MG request & configuration, DL PRS Measurement and Processing, Provide Location transmission and processing.
[11]	FR1: [17-5147.8] FR2: [15.5-5144.8]	Major Assumptions: Start and End States: RRC_CONNECTED, Without MG configuration, DL PRS periodicity = 4-5120ms, 1 DL PRS occasion, T=8ms DL PRS processing time. Major Components: Request Location reception and processing, DL PRS Measurement and Processing, Provide Location transmission and processing.

[15]	For UE capability-1: 62.97 ms ~ 297.11ms For UE capability-2: 61.17 ms ~ 293.68 ms	<p>Major assumptions:</p> <ul style="list-style-type: none"> - For PUSCH transmission: <ul style="list-style-type: none"> - Uplink switching gap is not configured. - No BWP switching - No overlapping symbols of the PUCCH and the scheduled PUSCH - # of PUSCH symbols = from 4 to 14 for Type A - # of PUSCH symbols = from 1 to 14 for Type B - For PDSCH transmission: <ul style="list-style-type: none"> - No overlapping symbols of the scheduling PDCCH and the scheduled PDSCH - # of PDSCH symbols = from 3 to 14 for Type A - # of PDSCH symbols = from 2 to 14 for Type B <p>Major components</p> <ul style="list-style-type: none"> -RRC processing time for LPP message at both gNB and UE (LPP request location information message, measurement gap request message, LPP provide location information message) -PRS measurement (LCM of PRS resource periodicity and repetition periodicity of the measurement gap) -If the latency components related with higher layer are excluded, the physical layer latency is described as follows: <ul style="list-style-type: none"> - For UE capability-1: 23.97ms ~ 249.11ms - For UE capability-2: 22.17ms ~ 245.68ms
[8]	FR1: 51.5ms	<p>Major Assumptions:</p> <p>Case 1, 15kHz, FR1, DL-TDOA Source UE/Destination NW Positioning technique DL-TDOA, type DL, mode UE-assisted, Initial and Final RRC States CONNECTED.</p> <p>Major Components:</p> <p>require measurement gap, measurement gap configuration, the delay between the time when DL PRS is received and the time when measurement gap configuration is received, the time from UE begins to measure PRS until the measurement result is ready to report, measurement reporting.</p>
[13]	FR1: [44.35 – 10500] ms FR2: [35.08 – 2118.93 ms]	<p>Major Assumptions:</p> <p>15 kHz SCS for FR1 120 kHz SCS for FR2 Source NW/ Destination NW. UE-assisted. Including MG configuration.</p> <p>Major components:</p> <p>DL PRS periodicity DL PRS processing time SR related steps</p>
[12]	FR1: 54.125ms for 60KHz FR2: 52.56ms for 120KHz	<p>Major Assumptions: 60KHz for FR1 and 120KHz for FR2</p> <p>Major components:</p> <p>Process Location Request reception, MG request & configuration, PRS measurement and processing PUSCH carrying measurement report</p>

[16]	FR1: 33ms	<p>Major assumptions:</p> <ul style="list-style-type: none"> 30kHz SCS Initial and final state: RRC_CONNECTED. The UE is configured with MG of 1.5ms, receives the PRS within the MG to conduct positioning measurement. The UE uses a configured grant having periodicity of 1ms to report the measurement. Best case scenario <p>Major components:</p> <ul style="list-style-type: none"> Decoding the LPP request location by the UE Decoding the MG request by the gNB Receiving the MG configuration and apply the configuration.
[10]	FR1: 129.07 ms	<p>Major assumptions:</p> <ul style="list-style-type: none"> 30kHz SCS / FDD Initial and final state: RRC_CONNECTED. DL PRS: 18 resources / 4 symbols per resource / 12 Comb-6 symbols per period. Periodicity – 20 ms. UE DL PRS processing capability – N = 0.5 ms (~12 symbols @30kHz), T = 8 ms Dynamic DL/UL scheduling based on SR – based on URLLC assumptions [3GPP 38.824, v16.0.0] Measurement gap: MGL = 5.5 ms, MGRP = 20ms DL PRS processing <ul style="list-style-type: none"> Nsample = 4 (RAN4 core measurements requirements) UE is expected to perform measurements on DL PRS resource 4 times (i.e. across 4 periods) Higher layer latency components (RRC/LPP processing) are included into the physical layer analysis <p>Major components:</p> <ul style="list-style-type: none"> MG configuration and alignment time DL PRS processing time and report delay Multiple DL/UL transactions for location request, assistance information, measurement gap request and configuration and associated UE/gNB higher layer processing delays (RRC/LPP) <p>Summary: 4.5714 (L1 components) + 36 (L2/L3 components) + 88.5 (DL PRS processing) = 129.07 ms (total)</p>

Table B.2-2: physical layer latency for Rel.16 UL-TDOA/DL-AOA UE-Assisted NR positioning

Source Reference to Tdoc #	Physical layer latency for UL-TDOA/UL-AOA, ms	Comments on major assumptions and physical layer latency components
[4]	FR1: 6.5-26ms (1 samp.) 66.5-86.5ms (4 samp)	Major assumptions: SRS periodicity is 20ms Major components SRS measurement
[5] 1	FR1: 30.5-2570.5 FR2: 650.5-10250.5	Major assumptions: FR1:SRS periodicity is {1, 2, 4, 5, 8, 10, 16, 20, 32, 40, 64, 80, 160, 320, 640, 1280, 2560}slots <ul style="list-style-type: none"> - 15kHz 1ms-2560ms - 30kHz 0.5ms-1280ms - 60kHz 0.25ms-640ms - 120kHz 0.125ms-320ms FR2: Multiple positioning occasion (4) and beam sweeping (8) <ul style="list-style-type: none"> - UL measurement equals to the periodicity of SRS $\times N_{RxBeam} \times N_{PosOccasion}$ gNB processing delay is assumed as zero ; The minimum periodicity of SRS is 20ms and the same as the DL minimum periodicity. Major components: SRS measurement; NRPPa process time
[5] 2	FR1: 11-43	Major assumptions: SRS is aperiodic and the slot offset of aperiodic is 0-32 slots <ul style="list-style-type: none"> - 15kHz 0ms-32ms - 30kHz 0ms-16ms - 60kHz 0ms-8ms - 120kHz 0ms-4ms Major components: SRS measurement; NRPPa process time; Activation;
[15]	For UE capability-1: 14.78ms ~ 20.14ms For UE capability-2: 14.42ms ~ 282.97ms	Major assumptions: <ul style="list-style-type: none"> - -For SRS transmission: One shot transmission (2 OS ~ 12 OS) - -For PDSCH transmission: <ul style="list-style-type: none"> - No overlapping symbols of the scheduling PDCCH and the scheduled PDSCH - # of PDSCH symbols = from 3 to 14 for Type A - # of PDSCH symbols = from 2 to 14 for Type B Major components -RRC processing time for LPP message at both gNB and UE (SRS configuration, SRS activation message) -When the latency related with higher layer is excluded, physical layer latency is described as follows: <ul style="list-style-type: none"> - For UE capability-1: 0.78ms ~ 2.64ms - For UE capability-2: 0.42ms ~ 2.07ms
[8]	FR1: 5ms	Major Assumptions: Case 2, 15kHz, FR1, UL-TDOA Source UE/Destination NW Positioning technique UL-TDOA, type UL, mode UE-assisted, Initial and Final RRC States CONNECTED Major Components: the time to activate the SRS transmission, the delay from effective time of SRS activation until UE begins to transmit SRS, the time from gNB begins to measure SRS until the measurement result is ready.

[13]	FR1: [2.78 – 81928.5] ms	<p>Major Assumptions: 15 kHz SCS Source NW/ Destination NW. Excluding SRS-Pos RRC configuration</p> <p>Major Components: SRS-Pos periodicity Processing of SRS-Pos at gNB/RP-only</p>
[13]	FR1: [2.78 – 81928.5] ms	<p>Major Assumptions: 15 kHz SCS Source NW/ Destination NW. Excluding SRS-Pos RRC configuration</p> <p>Major Components: SRS-Pos periodicity Processing of SRS-Pos at gNB/RP-only</p>
[13]	FR1: [2.35 – 81925] ms	<p>Major Assumptions: 15 kHz SCS Source NW/ Destination NW. Excluding SRS-Pos RRC configuration</p> <p>Major Components: SRS-Pos periodicity Processing of SRS-Pos at gNB/RP-only</p>
[12]	FR1: 23.25 ms for 60kHz FR2: 23.125ms for 120kHz	<p>Major Assumptions: 60KHz for FR1 and 120KHz for FR2.</p> <p>Major Components:</p> <ul style="list-style-type: none"> - gNB process NPPa measurement request - Configure SRS - SRS-Pos periodicity - gNB processing SRS
[16]	FR1: 12ms	<p>Major assumptions:</p> <ul style="list-style-type: none"> - Initial and final state: RRC_CONNECTED. - SRS transmission resources occur immediately after decoding the SRS configuration. - 30kHz SCS - Best case scenario <p>Major components:</p> <ul style="list-style-type: none"> - Decoding the SRS configuration message.
[10]	FR1: 18.77 ms	<p>Major assumptions:</p> <ul style="list-style-type: none"> - 30kHz SCS / FDD - Initial and final state: RRC_CONNECTED. - Dynamic DL/UL scheduling based on SR – see URLLC assumptions [3GPP 38.824, v16.0.0] - PUSCH: Any symbol, subject to slot boundary constraint (i.e. transmission does not cross slot boundary); Duration – 2, 4, 7 symbols (Type B mapping w/ front loaded DMRS) - PUCCH: 7 occasions per slot [1,0,1,0,1,0,1,0,1,0,1,0] for SR and HARQ feedback, Duration – 1 symbol. - No HARQ – initial transmission is successful - SRS for positioning: Single resource, 1 symbol duration, Periodicity – each slot - Higher layer latency components (RRC/LPP processing) are included into the physical layer latency analysis <p>Major components:</p> <ul style="list-style-type: none"> - SRS for positioning configuration - UE/gNB higher layer processing delays (RRC/LPP processing) <p>Summary = 2.7678 (L1 components) + 16 (L2/L3 components) = 18.7678 ms (total)</p>

Table B.2-3: physical layer latency for Rel.16 UE-Assisted Multi-RTT Positioning

Source Reference to Tdoc #	Physical layer latency for Multi-RTT, ms	Comments on major assumptions and physical layer latency components
[17]	[59-823]	Major assumptions: Connected state, FR1, (N,T) = (6,8) PRS capability Major components: Location Request Reception, MG Request & Configuration, PRS/MG Alignment, PRS processing capabilities
[4]	FR1: 51.5-66ms (1 samp.) 111.5-126.5ms (4 samp. CSSF = 1) 171.5-186ms (4 samp. CSSF = 2)	Major assumptions: PRS periodicity is 20ms MG is requested Major components PRS measurement
[4]	FR1: 171.5-178.5ms (1 samp.) 651.5-658.5ms (4 samp. CSSF = 1)	Major assumptions: PRS periodicity is 160ms MG is not requested (sharing with existing RRM gap 6ms/40ms) Major components PRS measurement
[5]	FR1: [94.5-14126.5] +T _{Align_DL_UL}	Major assumptions and components: For FR1: DL measurement & process delay = $(LCM(T_{PRS}, T_{measGap})) \cup (T_{Process\ time})$, PRS and MG is periodicity the minimum value is 22ms for $LCM(T_{PRS}, T_{measGap}) = 20ms$, (N,T) = (6,8) the maximum value is 11514 ms for $LCM(T_{PRS}, T_{measGap}) = 10240ms$, (N,T) = (6,1280) FR1:SRS periodicity is {1, 2, 4, 5, 8, 10, 16, 20, 32, 40, 64, 80, 160, 320, 640, 1280, 2560}slots 15kHz 1ms-2560ms 30kHz 0.5ms-1280ms 60kHz 0.25ms-640ms 120kHz 0.125ms-320ms T _{Align_DL_UL} : The alignment delay is the gap between End trigger of DL positioning and Start trigger of UL positioning. MG request and configuration Location Request and report

[15]	<p>For UE capability-1: 77.75 ms ~ 314.75 ms</p> <p>For UE capability-2: 75.59 ms ~ 311.75 ms</p>	<p>Major assumptions:</p> <ul style="list-style-type: none"> - For PUSCH transmission: <ul style="list-style-type: none"> - Uplink switching gap is not configured. - No BWP switching - No overlapping symbols of the PUCCH and the scheduled PUSCH - # of PUSCH symbols = from 4 to 14 for Type A - # of PUSCH symbols = from 1 to 14 for Type B - For PDSCH transmission: <ul style="list-style-type: none"> - No overlapping symbols of the scheduling PDCCH and the scheduled PDSCH - # of PDSCH symbols = from 3 to 14 for Type A - # of PDSCH symbols = from 2 to 14 for Type B - For SRS transmission: One shot transmission (2 OS ~ 12 OS) <p>Major components</p> <ul style="list-style-type: none"> - RRC processing time for LPP message at both gNB and UE (SRS configuration, SRS activation message, LPP request location information message, measurement gap request message, LPP provide location information message) - PRS measurement (LCM of PRS resource periodicity and repetition periodicity of the measurement gap) - When the latency related with higher layer is excluded, physical layer latency is described as follows: <ul style="list-style-type: none"> - For UE capability-1: 24.75 ms ~ 251.75ms - For UE capability-2: 22.59ms ~ 248.75ms
[16]	FR1: 45ms	<p>Major assumptions:</p> <p>Initial and final state: RRC_CONNECTED.</p> <p>The UE is configured with MG of 1.5ms, receives the PRS within the MG to conduct positioning measurement.</p> <p>The UE uses a configured grant having periodicity of 1ms to report the measurement.</p> <p>SRS transmission resources occur immediately after decoding the SRS configuration.</p> <p>30kHz SCS</p> <p>Best case scenario</p> <p>Major components:</p> <ul style="list-style-type: none"> Decoding the LPP request location by the UE Decoding the MG request by the gNB Receiving the MG configuration and apply the configuration. Receiving PRS in the MG Decoding the SRS configuration message.

[10]	140.84 ms	<p>Major assumptions: 30kHz SCS / FDD Initial and final state: RRC_CONNECTED. DL PRS: 18 resources / 4 symbols per resource / 12 Comb-6 symbols per period. Periodicity – 20 ms. UE DL PRS processing capability – N = 0.5 ms (~12 symbols @30kHz), T = 8 ms Dynamic DL/UL scheduling based on SR – based on URLLC assumptions [3GPP 38.824, v16.0.0] Measurement gap: MGL = 5.5 ms, MGRP = 20ms DL PRS processing Nsample = 4 (RAN4 core measurements requirements) UE is expected to perform measurements on DL PRS resource 4 times (i.e. across 4 periods) PUSCH: Any symbol, subject to slot boundary constraint (i.e. transmission does not cross slot boundary); Duration – 2, 4, 7 symbols (Type B mapping w/ front loaded DMRS) PUCCH: 7 occasions per slot [1,0,1,0,1,0,1,0,1,0,1,0] for SR and HARQ feedback, Duration – 1 symbol. No HARQ – initial transmission is successful SRS for positioning: Single resource, 1 symbol duration, Periodicity – each slot Higher layer latency components (RRC/LPP processing) are included into the physical layer latency analysis</p> <p>Major components: MG configuration and alignment time DL PRS processing time and report delay Multiple DL/UL transactions and associated UE/gNB RRC/LPP processing delays</p> <p>Summary: 7.3393 (L1 components) + 45 (L2/L3 components) + 88.5 (DL PRS processing) = 140.8393 (total)</p>
------	-----------	---

Table B.2-4: physical layer latency for Rel.16 UE-Assisted E-CID Positioning

Source Reference to Tdoc #	Physical layer latency for ECID, ms	Comments on major assumptions and physical layer latency components
[4]	FR1 8.5-15ms	Major assumptions: DL E-CID RRM measurement available Major components Higher layer signaling processing
[4]	FR1 6-26ms	Major assumptions: UL E-CID RRM measurement available Major components Higher layer signaling processing, or Additional AoA measurement at gNB
[7]	FR1 10.30 ms	Major assumptions: DL E-CID RRM measurement is available at UE side. Major components: UE interprets and applies the measurement configuration
[15]	For UE capability-1: 28.41 ms ~116.55 ms For UE capability-2: 27.33 ms ~ 115.05 ms	Major assumptions: <ul style="list-style-type: none"> - For PUSCH transmission: <ul style="list-style-type: none"> - Uplink switching gap is not configured. - No BWP switching - No overlapping symbols of the PUCCH and the scheduled PUSCH - # of PUSCH symbols = from 4 to 14 for Type A - # of PUSCH symbols = from 1 to 14 for Type B Major components <ul style="list-style-type: none"> - RRC processing time for LPP message at both gNB and UE (LPP provide location information message) When the latency related with higher layer is excluded, physical layer latency is described as follows: <ul style="list-style-type: none"> - For UE capability-1: 2.41ms ~ 85..55ms (FR1) - For UE capability-2: 1.33ms ~ 84.05ms (FR1)

Table B.2-5: physical layer latency for Rel.16 UE-Based DL Only Positioning

Source Reference to Tdoc #	Physical layer latency for UE-based DL only positioning, ms	Comments on major assumptions and physical layer latency components
[17]1	[46-811]	Major assumptions: Start from RRC Connected, FR1, (N,T)=(6,8), External client Major components: Location Request reception, MG request & configuration, MG/PRS alignment, PRS processing capabilities
[17]2	[8-780]	Major assumptions: Start from RRC Inactive, FR1, (N,T)=(6,8) , Internal client Major components: PRS alignment time, PRS processing capabilities
[4]	FR1 51-58.5ms (1 samp.)	Major assumptions: PRS periodicity is 20ms MG is requested MO-LR Major components PRS measurement
[5] 1	FR1: [66-11558] FR2 : [730-328998]	Major assumptions and components: For FR1: DL measurement & process delay= $(LCM(T_{PRS}, T_{measGap})) \cup (T_{Process\ time})$, PRS and MG is periodicity MG request and configuration Calculation of Location Estimate at the UE Location Request and report MT-LR
[5] 2	FR1: [55.5-11547.5] FR2 : [719.5-328987.5]	Major assumptions and components: For FR1: DL measurement & process delay= $(LCM(T_{PRS}, T_{measGap})) \cup (T_{Process\ time})$, PRS and MG is periodicity MG request and configuration Location Request Calculation of Location Estimate at the UE MO-LR
[11]	FR1: [29-207.8] FR2: [27.5 - 204.8]	Major Assumptions: Start and End States: RRC_CONNECTED, MGRP = 20ms-160ms, 1 DL PRS occasion, T=8ms-160ms PRS processing time, Request and provide location information messages omitted. Major Components: MG request & configuration, DL PRS Measurement and Processing.
[11]	[8-5120]	Major Assumptions: Start and End States: RRC_CONNECTED, Without MG configuration, DL PRS periodicity=4-5120ms, 1 DL PRS occasion, T=8ms DL PRS processing time, Request and provide location information messages omitted. Major Components: DL PRS Measurement and Processing.
[12]	44ms	Major Assumption: - Start time: UE sends MG request - End time: UE finish location calculation Major component: - MG request and configuration - Measurement gap periodicity - UE calculating location
[16]	FR1 : [39-61] ms for Alt. 1, [50-72] ms for Alt. 2, [22-44] ms for Alt. 3, where different alternatives correspond to different starting points for latency evaluation of UE-B positioning	Major assumptions: - 30kHz SCS - Initial and final state: RRC_CONNECTED. - The UE is configured with MG of 1.5ms, receives the PRS within the MG to conduct positioning measurement. (for Alt 1 & 2) - The UE uses a configured grant having periodicity of 1ms to report the measurement. (for Alt 1 & 2 & 3) - Best case scenario Major components: - Decoding the LPP request location by the UE (for Alt 2) - Decoding the MG request by the gNB (for Alt 1 & 2) - Receiving the MG configuration and apply the configuration. (for Alt 1 & 2) - UE calculating location (for Alt 1 & 2 & 3)

Annex C:

Appendix to Performance evaluations for R17 performance targets

C.1 Performance analysis of Rel-16 positioning solutions

See separate word file.

C.2 Performance of studied NR positioning enhancements

See separate word file.

C.3 Efficiency analysis for NR positioning enhancements

See separate word file.

Annex D: Change history

Change history							
Date	Meeting	TDoc	CR	Rev	Cat	Subject/Comment	New version
2020-05	RAN1#101-e	R1-2004948				Baseline TR skeleton.	0.0.1
2020-10	RAN1#103-e	R1-2009430				Update of TR based on RAN1#101-e and RAN1#102-e agreements.	0.1.0
2020-10	RAN1#103-e	R1- 2009544				Update of TR based on RAN1#103-e agreements.	0.1.1
2020-11	RAN1#103-e	R1- 2009670				Update of TR based on RAN1#103-e agreements.	0.2.0
2020-11	RAN1#103-e	R1- 2009745				Update of TR based on RAN1#103-e agreements.	0.3.0
2020-11	RAN1#103-e	R1- 2009842				Update of TR based on RAN1#103-e agreements.	0.4.0
2020-12	RAN#90e	RP- 202588				Presentation of v1.0.0 for information at RAN#90e	1.0.0
2021-03	RAN1#104-e	R1- 2102262				Update of TR based on RAN2#113-e agreements.	1.1.0