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| Technical Report |
| 3rd Generation Partnership Project;  Technical Specification Group Radio Access Network;  Study on NR Positioning Enhancements;  (Release 17) |
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For definitive guidance on drafting 3GPP TSs and TRs, see [3GPP TS 21.801](http://www.3gpp.org/DynaReport/21801.htm) supplemented by the 3GPP web page <http://www.3gpp.org/specifications-groups/delegates-corner/writing-a-new-spec>.

Ensure all blue guidance text is removed before submitting the TS/TR to the TSG for approval.

# Foreword

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

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

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where:

x the first digit:

1 presented to TSG for information;

2 presented to TSG for approval;

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

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

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

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

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

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

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

**should** indicates a recommendation to do something

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

**may** indicates permission to do something

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

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

**can** indicates that something is possible

**cannot** indicates that something is impossible

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

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

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

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

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

In addition:

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

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

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

# 1 Scope

The present document captures the findings of the study item "Study on 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] R1-2009361 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

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[x] <doctype> <#>[ ([up to and including]{yyyy[-mm]|V<a[.b[.c]]>}[onwards])]: "<Title>".

# 3 Definitions of terms, symbols and abbreviations

This clause and its three subclauses are mandatory. The contents shall be shown as "void" if the TS/TR does not define any terms, symbols, or abbreviations.

## 3.1 Terms

For the purposes of the present document, the terms given in 3GPP 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 3GPP TR 21.905 [1].

**example:** text used to clarify abstract rules by applying them literally.

## 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 3GPP 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 3GPP TR 21.905 [1].

<ABBREVIATION> <Expansion>

# 4 General description of NR positioning

*(General description of NR positioning up to release 16 & NR positioning enhancements in rel17)*

# 5 Target requirements for NR positioning enhancements in Rel-17

## 5.1 Target requirements

## 5.2 Performance evaluation metrics

(Includes horizontal accuracy vertical accuracy and other 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

### 5.2.2 Vertical accuracy

### 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 |  | 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

#### 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 company to detail their methodology (including the power model) for evaluation.

# 6 Additional scenarios and channel models for NR positioning enhancements

*From justification, for the evaluation of solutions, the Rel-16 scenarios and channel models in TR 38.855 are reused where applicable, and additional scenarios for IIoT use cases should be defined.*

*from objective 1a. Includes definition of additional scenarios (e.g. (I)IoT) based on TR 38.901 to evaluate the performance for the use cases e.g. (I)IoT)*

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  - 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:  - 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:  - 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  – That is, the range of timing errors is [-T2, T2]  – T1: 0ns (perfectly synchronized), 50ns (Optional) | |
| UE/gNB RX and TX timing error | (Optional) The UE/gNB RX and TX timing error, in FR1/FR2, can be modeled as a truncated Gaussian distribution with zero mean and standard deviation of T1 ns, with truncation of the distribution to the [-T2, T2] range, and with T2=2\*T1:   * T1: [X] ns for gNB and [Y] ns for UE * X and Y are up to companies * Note: RX and TX timing errors are generated per panel independently   Apply the timing errors as follows:   * For each UE drop,   + For each panel (in case of multiple panels)     - Draw a random sample for the Tx error according to [-2\*Y,2\*Y] and another random sample for the Rx error according to the same [-2\*Y,2\*Y] distribution. * For each gNB   + For each panel (in case of multiple panels)     - Draw a random sample for the Tx error according to [-2\*X,2\*X] and another random sample for the Rx error according to the same [-2\*X,2\*X] distribution. * Any additional Time varying aspects of the timing errors, if simulated, can be left up to each company to report. * For UE evaluation assumptions in FR2, it is assumed that the UE can receive or transmit at most from one panel at a time with a panel activation delay of 0ms. | |
| Note 1: According to 3GPP TR 38.802  Note 2: According to 3GPP 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 1and 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=120m x W=60m): D=20m  - for the big hall (L=300m x W=150m): D=50m | | |
| 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=0.5λ – Note 1 | (M, N, P, Mg, Ng) = (4, 8, 2, 1, 1), dH=dV=0.5λ – 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]m, where X2 = 2m for scenario 1(Inf-SH) and X2= 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,), 8}. | | |
| Clutter parameters: {density , height ,size } | | 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 3GPP 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, companies may provide the details of their model, if any.

# 7 Studied NR positioning enhancements

*(from objective 1c. Includes positioning techniques, DL/UL positioning reference signals, signalling and procedures for improved accuracy, reduced latency, network efficiency, and device efficiency for both RAN1 and RAN2.  
Enhancements to Rel-16 positioning techniques, if they meet the requirements, will be prioritized, and new techniques will not be considered in this case. )*

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 and 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

# 8 Performance evaluations for Rel-17 targets

## 8.1 Performance analysis of Rel-16 positioning solutions

*Including accuracy and latency (objective 1b) performance, compared to rel17 performance targets*

### 8.1.1 Positioning accuracy analysis

### 8.1.2 Physical layer latency analysis for Rel-16

## 8.2 Performance analysis of studied NR positioning enhancements

*Including performance of positioning techniques, DL/UL positioning reference signals, signalling and procedures for improved accuracy, reduced latency ((objective 1c).*

## 8.3 Efficiency analysis for NR positioning enhancements

In this report, Network efficiency and UE efficiency is evaluated either via analytically or via simulations.

## 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 [12] out of [17] sources for FR1 and by [9] sources out of [17] for FR2
* For NR positioning evaluations in FR1 band, the following is observed with respect to horizontal positioning accuracy:
  1. Accuracy of ≤ [0.2m @ 90%](mailto:0.2m@90%25) is achieved in contributions from [3] sources and is not achieved in contributions from [9] sources
  2. Accuracy of ≤ [0.5m @ 90%](mailto:0.2m@90%25) is achieved in contributions from [7] sources and is not achieved in contributions from [5] sources
* For NR positioning evaluations in FR2 band, the following is observed with respect to horizontal positioning accuracy:
  1. Accuracy of ≤ [0.2m @ 90%](mailto:0.2m@90%25) is achieved in contributions from [7] sources and is not achieved in contributions from [2] sources
  2. Accuracy of ≤ [0.5m @ 90%](mailto:0.2m@90%25) is achieved in contributions from [9] sources 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:
  1. Accuracy of ≤ 1m @ 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:
  1. Accuracy of ≤ 1m @ 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:
  1. Accuracy of ≤ 0.2m @ 90% is achieved in contribution from [1] source ([8]) and is not achieved in contributions from [13] sources ([4], [6], [7], [9], [12], [13], [14], [19], [20], [17], [5], [10], [18])
  2. Accuracy of ≤ 0.5m @ 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:
  1. Accuracy of ≤ 0.2m @ 90% is achieved in contributions from [3] sources ([6], [17], [5]) and is not achieved in contributions from [6] sources ([4], [7], [8], [14], [20], [10])
  2. Accuracy of ≤ 0.5m @ 90% is achieved in contributions from [3] sources ([6], [17], [5]) and is not achieved in contributions from [6] sources ([4], [7], [8], [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:
  1. Accuracy of ≤ 1m @ 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:
  1. Accuracy of ≤ 1m @ 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], [5], [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 impairements) 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 ([5] R1-2007666) has analyzed aggregation of 2 frequency layers for different time offset values and observed that:
* For the case without impairements 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 impairements 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] ([11],[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], Lenovo, [12], [16])
* Summary of physical layer latency for Rel.16 DL-only UE-based NR positioning in FR2 was provided by [2] sources ([5], Lenovo)
* For evaluation in FR1,
  + results from [4] sources ([4], [5], [12], [16]) out of [6] sources ([17], [4], [5], Lenovo, [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], Lenovo, [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], Lenovo) 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], Lenovo) 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

# 9 Positioning integrity and reliability

*From objective 2: Includes solutions necessary to support integrity and reliability of assistance data and position information:*

# 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).

## 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.

## 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 and 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 mitigationEnhancements 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 Aperiodic reception of DL PRS

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 would correspond to DCI-triggered reception

# 11 Conclusions

Annex A:  
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- 200NNNN |  |  |  | Update of TR based on RAN1#103-e agreements. | 0.2.1 |

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 |
| 2.0ns | 2.0ns | 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 |
| 0.5ns | 5ns | 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 Δτ (RTT) | FR1 | Off at gNB  Off at UE | 1 ns | 1 ns | No |
| [17], UMI with Δτ (RTT) | FR1 | Off at gNB  Off at UE | 2 ns | 2 ns | No |
| [17], UMI with Δτ (RTT) | FR1 | Off at gNB  Off at UE | 5 ns | 5 ns | No |
| [17], UMI with Δτ (RTT) | FR1 | Off at gNB  Off at UE | 10 ns | 10 ns | No |
| [17], UMI without Δτ (RTT) | FR1 | Off at gNB  Off at UE | 2 ns | 2 ns | Yes |
| [17], UMI without Δτ (RTT) | FR1 | Off at gNB  Off at UE | 5 ns | 5 ns | No |
| [17], UMI without Δτ (RTT) | FR1 | Off at gNB  Off at UE | 10 ns | 10 ns | No |

## B.2 Evaluation of horizontal positioning accuracy with gNB/UE TX/RX timing error

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]  R1-2007665 | FR1:  [64-11556]  FR2：  [728-328996] | Major assumptions and components:  For FR1: DL measurement &process delay=**,** PRS and MG is periodicity  The minimum value is 22ms for **，**(N,T) = (6,8)  The maximum value is 11514 ms for **，**(N,T) = (6,1280)  For FR2:  **,** ,  The minimum value is 20\*4\*8+2ms =642ms  The maximum value is (10240+1280-6)=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] | FR1:  For UE capability-1:  73.12+[X]ms ~ 217.12+[X]ms  For UE capability-2:  71.68+ [X]ms ~ 215.26+[X]ms | Major assumptions:  -For PUSCH transmission:  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:  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  -[X]: Processing delay at gNB in terms of physical layer (Up to gNB capability)  Major components  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:  For UE capability-1: 23.12ms ~ 167.12ms (FR1)  For UE capability-2: 21.68ms ~ 165.26ms (FR1) |
| [8] | FR1: 51.5ms | Major Assumptions:  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.  Major Components:  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. |
| [13] | FR1: [44.35 – 10500] ms  FR2: [35.08 – 2118.93 ms] | Major Assumptions:  15 kHz SCS for FR1  120 kHz SCS for FR2  Source NW/ Destination NW. UE-assisted. Including MG configuration.  Major components:  DL PRS periodicity  DL PRS processing time  SR related steps |
| [12] | FR1: 54.125ms for 60KHz  FR2: 52.56ms for 120KHz | Major Assumptions: 60KHz for FR1 and 120KHz for FR2  Major components:  Process Location Request reception,  MG request & configuration,  PRS measurement and processing  PUSCH carrying measurement report |
| [16] | FR1: 33ms | 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.  The UE uses a configured grant having periodicity of 1ms to report the measurement.  Best case scenario  Major components:  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 | 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)  Higher layer latency components (RRC/LPP processing) are included into the physical layer analysis  Major components:  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)  Summary: 4.5714 (L1 components) + 36 (L2/L3 components) + 88.5 (DL PRS processing) = 129.07 ms (total) |

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 |
| vivo 1  R1-2007665 | 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  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 measurement equals to the periodicity of SRS  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 |
| vivo 2  R1-2007665 | FR1:  11-43 | Major assumptions:  SRS is aperiodic and the slot offset of aperiodic is 0-32 slots  15kHz 0ms-32ms  30kHz 0ms-16ms  60kHz 0ms-8ms  120kHz 0ms-4ms  Major components:  SRS measurement;  NRPPa process time;  Activation; |
| LG (R1-2008416) | FR1:  For UE capability-1:  31.49+[Y] ms ~ 34.42+[Y] ms  For UE capability-2:  30.77+[Y] ms ~ 33.28+[Y] ms | Major assumptions:  -For SRS transmission:  One shot transmission (2 OS ~ 12 OS)  -For PDSCH transmission:  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  -[Y]: Processing delay at gNB in terms of physical layer (Up to gNB capability)  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:  For UE capability-1: 1.49ms ~ 4.42ms (FR1)  For UE capability-2: 0.77ms ~ 3.28ms (FR1) |
| CATT(R1-2007859) | 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. |
| Nokia (R1-2009555) | FR1: [2.78 – 81928.5] ms | Major Assumptions: 15 kHz SCS  Source NW/ Destination NW. Excluding SRS-Pos RRC configuration  Major Components:  SRS-Pos periodicity  Processing of SRS-Pos at gNB/RP-only |
| OPPO | FR1: 23.25 ms for 60kHz  FR2: 23.125ms for 120kHz | Major Assumptions: 60KHz for FR1 and 120KHz for FR2.  Major Components:  gNB process NPPa measurement request  Configure SRS  SRS-Pos periodicity  gNB processing SRS |
| Interdigital  (R1-2008489) | FR1: 12ms | Major assumptions:  Initial and final state: RRC\_CONNECTED.  SRS transmission resources occur immediately after decoding the SRS configuration.  30kHz SCS  Best case scenario  Major components:  Decoding the SRS configuration message. |
| Intel Corporation  R1-2007945 | FR1: 18.77 ms | Major assumptions:  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 [1,0,1,0,1,0,1,0,1,0,1,0,1,0] 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  Major components:  SRS for positioning configuration  UE/gNB higher layer processing delays (RRC/LPP processing)  Summary = 2.7678 (L1 components) + 16 (L2/L3 components) = 18.7678 ms (total) |

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 |
| Qualcomm | [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 |
| vivo 1  R1-2007665 | FR1:  [94.5-14126.5] + | Major assumptions and components:  For FR1: DL measurement &process delay =, PRS and MG is periodicity  the minimum value is 22ms for ，(N,T) = (6,8)  the maximum value is 11514 ms for ，(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  : 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 |
| LG (R1-2008416) | FR1:  For UE capability-1:  145.34ms+[Z] ~ 293.32+[Z]ms  For UE capability-2:  142.8+[Z]ms ~  289.75+[Z] ms | Major assumptions:  -For PUSCH transmission:  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:  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)  -[Z]: Processing delay at gNB in terms of physical layer (Up to gNB capability)  Major components  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:  For UE capability-1: 25.34ms ~ 173.32ms (FR1)  For UE capability-2: 22.8ms ~169.75ms (FR1) |
| Interdigital  (R1-2008489) | FR1: 45ms | Major assumptions:  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.  SRS transmission resources occur immediately after decoding the SRS configuration.  30kHz SCS  Best case scenario  Major components:  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. |
| Intel Corporation  R1-2007945 | 140.84 ms | 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 [1,0,1,0,1,0,1,0,1,0,1,0,1,0] 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  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  Summary:  7.3393 (L1 components) + 45 (L2/L3 components) + 88.5 (DL PRS processing) = 140.8393 (total) |

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 |
| ZTE | 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 |
| LG (R1-2008416) | FR1:  For UE capability-1:  21.56+[M]ms ~ 23.56+[M] ms  For UE capability-2:  20.84+[M] ms~22.63+[M] ms | Major assumptions:  -For PUSCH transmission:   * 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   -[M]: Processing delay at gNB in terms of physical layer (Up to gNB capability)  Major components   * 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:   * For UE capability-1: 1.56ms ~ 3.56ms (FR1) * For UE capability-2: 0.84ms~2.63ms (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 |
| Source #1: | FR1:  FR2: | Major assumptions:  Major components: |
| Qualcomm1 | [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 |
| Qualcomm2 | [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 |
| vivo 1  R1-2007665 | FR1:  [66-11558]  FR2：  [730-328998] | Major assumptions and components:  For FR1: DL measurement &process delay=, PRS and MG is periodicity  MG request and configuration  Calculation of Location Estimate at the UE  Location Request and report  MT-LR |
| vivo 2  R1-2007665 | FR1:  [55.5-11547.5]  FR2：  [719.5-328987.5] | Major assumptions and components:  For FR1: DL measurement &process delay=, PRS and MG is periodicity  MG request and configuration  Location Request  Calculation of Location Estimate at the UE  MO-LR |
| Lenovo, Motorola Mobility1 (R1-2007997) | 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. |
| Lenovo, Motorola Mobility2 (R1-2007997) | [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. |
| OPPO | 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 |
| Interdigital  (R1-2008489) | 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) |
|  |  |  |
|  |  |  |