**3GPP TSG RAN WG1 Meeting #103-E R1-200xxxx**

**e-Meeting, October 26th – November 13th, 2020**

**Source: Moderator (Intel Corporation)**

**Title: Feature lead summary for evaluation of NR Positioning enhancements - AI 8.5.2**

**Agenda item: 8.5.2**

**Document for: Discussion and Decision**

# Introduction

In this contribution, we provide overview of evaluation results provided in contributions submitted for Rel.17 NR Positioning Enhancements WI [1] - [17]. In addition, we try to formulate tentative conclusions and proposals for discussions based on provided results.

Please refer to Section 2 if you are interested to check the overview of the contributions. The summary of the discussed aspects and tentative proposals for further discussion are provided in Section 3.

# Review of Submitted Contributions

In this contribution, we provide overview of evaluation results provided in contributions submitted for Rel.17 NR Positioning Enhancements WI. In addition, we try to formulate tentative conclusions and proposals for discussions based on provided results.

## Source #1

In [[1], Huawei, HiSi], the evaluation of Rel.16 positioning methods and the Rel.17 potential enhancements are provided. The positioning accuracy, latency, network efficiency, and UE efficiency are analysed. The evaluations are performed in FR1 and FR2 frequency bands.

The following set of scenarios is considered:

* InF-SH/InF-DH baseline scenarios, no UE/gNB calibration error
* InF-DH, variable UE/gNB height
* InF-SH/InF-DH with UE/gNB calibration error

The following positioning techniques are evaluated:

* FR1 band:
  + DL-TDOA, UL-TDOA, UL-TDOA + UL-AOA, Multi-RTT
* FR2 band:
  + DL-TDOA, DL-TDOA + DL-AOD, UL-TDOA + UL-AOA, Multi-RTT

**Rel.16 positioning methods evaluation**

**Accuracy**

*InF-SH/InF-DH baseline scenarios – no UE/gNB calibration error*

Observations:

* The hybrid positioning can help to improve the positioning accuracy, e.g. UL-TDOA+UL-AOA, DL-TDOA+DL-AOD
* For InF-SH, the accuracy of less than 0.2m@90% can be achieved with DL-TDOA+DL-AOD and UL-TDOA+UL-AOA in FR2
* For InF-SH, the accuracy of less than 0.5m@90% can be achieved with UL-TDOA+UL-AOA in FR1 and Multi-RTT in FR2
* For InF-DH, the accuracy target of less than 0.5m@90% cannot be achieved in either FR1 or FR2

*InF-DH – variable UE/gNB height*

Observations:

* For modified InF-DH, the accuracy of less than 0.5m@90% cannot be achieved without NLOS/LOS detection

*InF-SH/InF-DH with UE/gNB calibration errors*

Observations:

* The positioning accuracy of Rel-16 Multi-RTT is deteriorated greatly than other positioning methods
* The positioning accuracy of less than 0.5m@90% can be achieved with UL-TDOA+UL-AOA
* The positioning accuracy of Rel-16 UL-AOA is deteriorated greatly with gNB Rx angle error

**Physical layer latency**

Positioning methods:

* UE-assisted DL-only positioning (DL-TDOA and/or DL-AoD) and Multi-RTT positioning:
  + Gap request (20ms PRS):
    - 1 sample - 51.5-66 ms
    - 4 samples/CSSF = 1 - 111.5-126.5 ms
    - 4 samples/CSSF = 2 - 171.5-186 ms
  + No gap Request (160ms PRS):
    - 1 sample - 171.5-178.5 ms
    - 4 samples/CSSF = 1 - 651.5-658.5 ms
* UL-only positioning (UL-TDOA and/or UL-AoA):
  + 1 sample - 6.5-26 ms
  + 4 samples - 66.5-86.5 ms
* DL E-CID positioning:
  + 8.5-15 ms
* UL E-CID positioning:
  + 6-26 ms
* UE-based DL-only positioning:
  + Gap request and 1 sample - 51-58.5ms (1 samp.)

Observations:

* Physical layer latency of less than 10 ms can be achieved by UL E-CID (6ms), UL-only (6.5ms), and DL E-CID (8.5ms)

**Rel.17 potential enhancements**

**LOS/NLOS classification**

Observations (for modified InF-DH):

* The LOS/NLOS detection achieves close performance to the Ideal LOS/NLOS detection
* Both the LOS/NLOS detection and the Ideal LOS/NLOS detection achieve the accuracy of less than 0.5m@90%
* The LOS/NLOS detection method achieves higher accuracy than the traditional RAIM method by tagging the channel as LOS or NLOS

**PRS/SRS frequency aggregation**

Observations:

* PRS/SRS frequency 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 symbol PRS**

Observations:

* The single PRS symbol transmission achieves almost the same performance with that of multiple PRS symbols for InF-SH scenarios

**Network efficiency**

PRS configuration:

* PRS transmission periodicity is 160ms
* PRS numerology is 30kHz
* 8 PRS resources with 12 symbols or 4 symbols per PRS resource
* The PRS bandwidth is 100MHz

By reducing the PRS symbols from 12 and 4 to 1 for comb-12 and comb-4, respectively, the overhead of PRS transmission is reduced by 11/12 and 3/4, respectively.

**PRS punctured by SSB**

Observations:

* When the PRS center 20RBs are punctured by SSB, the positioning accuracy is almost not affected

**IDLE/INACTIVE state positioning**

Observations:

* IDLE/INACTIVE state positioning can save about 7%-40% power consumption compared to C-DRX configuration

**Angle of arrival with uniform linear array**

Observations:

* The positioning accuracy is greatly reduced using legacy AOA reporting
* The enhanced AOA reporting can approach the UPA positioning accuracy

**E-CID enhancement**

Observations for accuracy:

* The positioning accuracy of E-CID (RTT+AOA) approaches the Multi-RTT with Ideal LOS/NLOS detection

Latency analysis:

* Assumptions:
  + Source NW/Destination NW
  + Positioning technique UL-E-CID, type DL+UL, mode UE-A,
  + Initial and Final RRC States CONNECTED
  + Assuming UE Rx – Tx time difference is already available
* Components:
  + Start trigger
  + gNB Rx higher layer processing: 3 ms
  + gNB Rx – Tx time difference measurement and AoA measurements: 0 – 20 ms
  + gNB Tx higher layer processing: 3 ms
  + End trigger
* Total value: 6 – 26 ms
* Assumptions:
  + Source NW/Destination NW
  + Positioning technique UL-E-CID, type DL+UL, mode UE-A,
  + Initial and Final RRC States CONNECTED
  + Assuming UE Rx – Tx time difference is not available
* Components:
  + Start trigger
  + gNB Rx higher layer processing: 3 ms
  + gNB Tx higher layer processing: 3 ms
  + PDSCH scheduling: 0.5 – 1 ms
  + UE Rx higher layer processing: 10 ms
  + UE Rx – Tx time difference measurement/gNB Rx – Tx time difference measurement and AoA measurements: 20 ms
  + UE Tx higher layer processing: 3 ms
  + PUSCH scheduling: 0.5 – 7.5 ms
  + gNB Rx higher layer processing: 3 ms
  + gNB Tx higher layer processing: 3 ms
  + End trigger
* Total value: 46 - 53.5 ms

**Network efficiency**

Since enhanced E-CID may only use existing communication signals, it has not extra positioning overhead.

## Source #2

In [[2], BUPT], the evaluation of Rel.16 positioning methods is provided. The positioning accuracy is analyzed in FR1 and FR2 bands.

The following set of scenarios is considered:

* InF-SH/InF-DH baseline scenarios

The following positioning techniques are evaluated:

* FR1 band:
  + DL-TDOA
* FR2 band:
  + DL-TDOA

Observations (for horizontal accuracy):

* Commercial horizontal accuracy requirements 1 m @ 90 %: met for all scenarios
* IIoT horizontal accuracy requirements of 0.2 m @ 90 %:
  + InF-SH, FR1: not met
  + InF-DH, FR1: not met
  + InF-SH, FR2: not met
  + InF-DH, FR2: met
* IIoT horizontal accuracy requirements of 0.5 m @ 90 %:
  + InF-SH, FR1: not met
  + InF-DH, FR1: met
  + InF-SH, FR2: met
  + InF-DH, FR2: met

## Source #3

In [[3], ZTE], the evaluation of Rel.16 positioning methods and Rel.17 enhancements, including LOS/NLOS classification, are provided. The positioning accuracy, and physical layer latency are analysed. The evaluations are performed in FR1 and FR2 frequency bands.

The following set of scenarios is considered:

* InF-SH/InF-DH baseline scenarios
* With and without gNB TX calibration error (0 ns, 0.5 ns, 1.0 ns, 2.0 ns)

The following positioning techniques are evaluated:

* FR1 band:
  + DL-TDOA
* FR2 band:
  + DL-TDOA

**Rel.16 positioning methods evaluation**

Observations (horizontal accuracy, Rel.16 DL-TDOA):

* InF-SH scenario:
  + The positioning accuracy of UE inside convex hull is slightly better than the case where all UEs are uniformly distributed over the factory, because the high-quality links for positioning are always enough under high LOS probability scenario.
  + When there is no network synchronization error and gNB Tx calibration error, the horizontal positioning accuracy of 90% UEs inside convex hull are less than 0.568 m in FR1, while the value is 0.090 m in FR2.
  + The sub-meter level horizontal positioning accuracy at the percentile of 90% UEs will be fulfilled, if gNB Tx calibration error is larger than 1 ns in FR1 and 2 ns in FR2.
* InF-DH scenario:
  + The positioning accuracy of UE inside convex hull is much better than the case where all UEs are uniformly distributed over the factory, because the high-quality links for positioning may not be enough under low LOS probability scenario.
  + When there is no network synchronization error and gNB Tx calibration error, sub-meter level horizontal positioning accuracy will be fulfilled for UEs inside convex hull at the percentile of 67% in FR1 and 80% in FR2.
  + gNB Tx calibration error significantly degrades the positioning performance, e.g. 1ns in FR1 and 2 ns in FR2.

Observations (vertical accuracy, Rel.16 DL-TDOA):

* For vertical positioning accuracy based on Rel-16 DL-TDOA method, all cases of InF-SH scenario can meet the loose vertical accuracy requirement (i.e. 1 m for 90% of UEs), but in the InF-DH scenario, only 67% UEs in FR1 and 80% UEs in FR2 can meet sub-meter level requirement.

**Rel.17 enhancements with LOS identification**

Types of used assistance information:

* Ideal LOS identification
* Rician K-factor as assistance information
* Coherence bandwidth as assistance information

Observations (InF-DH, LOS identification):

* When positioning is done without assistance information, the positioning performance degrades rapidly for UEs connected with small LOS communication links.
* If ideal classification of LOS and NLOS links is assumed, all cases meet sub-meter level positioning accuracy requirement.
* By utilizing Rician K-factor and coherence bandwidth as assistance information, positioning accuracy is significantly improved compared to without such assistance information, and sub-meter level positioning accuracy requirement can be fulfilled at the percentile of 90% UEs in FR2.

**Latency**

Basic assumptions (for latency calculation):

* UE is already in RRC\_CONNECTED state, and some LPP messages such as capability data are not considered in physical layer latency.
* The latency due to any additional delays (e.g. RACH procedures, RRC reconfiguration, handover, etc.) are ignored.

*UE-assisted positioning method based on DL-TDOA*

* Assumptions:
  + Source [UE]/Destination [NW]
  + Positioning technique [DL-TDOA], type [DL], mode [UE-A]
  + Initial and Final RRC States [CONNECTED]
* Components:
  + Start trigger (step 1)
  + UE decodes and applies the Location Request (step 2): 10 ms
  + Measurement gap request (step 3):
    - UL user plane latency NR FDD with grand free transmission:
      * 30 kHz: 0.43 ms
      * 60 kHz: 0.30 ms
    - UL user plane latency NR TDD with grant free transmission:
      * 30 kHz: 1.09 ms
      * 60 kHz: 0.64 ms
  + Serving gNB decodes and interprets the measurement gap request (step 4): 3 ms
  + Measurement gap configuration (step 5):
    - DL user plane latency for NR FDD:
      * 30 kHz: 0.37 ms
      * 60 kHz: 0.27 ms
    - DL user plane latency for NR TDD:
      * 30 kHz: 0.45 ms
      * 60 kHz: 0.32 ms
  + UE interprets and applies the measurement gap configuration (step 6): 10 ms
  + UE positioning measurement (step 7):
    - FR1 band: 82 ms
    - FR2 band: 644 ms
  + UE positioning measurement (step 7): the same as measurement gap request (see above)
  + End trigger (step 9)
* Total values:
  + Total values (1): 106.23 ms (FDD, 30 kHz)
  + Total values (2): 667.87 ms (FDD, 60 kHz)
  + Total values (3): 107.63 ms (TDD, 30 kHz)
  + Total values (4): 668.60 ms (TDD, 60 kHz)

Measurement period requirements for DL-TDOA method:

* MGRP (Measurement Gap Repetition Period):
  + FR1 band: 20 ms
  + FR2 band: 20 ms
* MGL (Measurement Gap Length):
  + FR1 band: 4 ms
  + FR2 band: 4 ms
* TPRS (DL PRS periodicity):
  + FR1 band: 4 ms
  + FR2 band: 4 ms
* (N, T) (Duration of DL PRS symbols N in units of ms a UE can process every T ms):
  + FR1 band: (4, 20) ms
  + FR2 band: (4, 20) ms
* L (Number of positioning frequency layers):
  + FR1 band: 1
  + FR2 band: 1
* Number of TRPs:
  + FR1 band: 4
  + FR2 band: 4
* SCS (Sub-carrier Spacing):
  + FR1 band: 30 kHz
  + FR2 band: 60 kHz
* LPRS (the duration of DL PRS symbols within any a window):
  + FR1 band: 2 ms
  + FR2 band: 4 ms
* CCFSPRS (carrier-specific scaling factor):
  + FR1 band: 1
  + FR2 band: 1
* NRxBeam (UE Rx beam sweeping factor):
  + FR1 band: 1
  + FR2 band: 8
* Nsample (Number of PRS RSTD samples):
  + FR1 band: 4
  + FR2 band: 4
* Total measurement period:
  + FR1 band: 82 ms
  + FR2 band: 644 ms

*UE-based positioning method based on DL-TDOA*

Components (several cases for start and end triggers):

* Case 1:
  + Start trigger:
    - Transmission of the PDSCH from the gNB carrying the LPP Request Location Information
  + End trigger:
    - Successful decoding of the PUSCH at gNB carrying the LPP Provide Location Information message
  + Difference from UE-assisted method:
    - Update the start and end triggers accordingly
    - All other steps are the same as UE-assisted positioning
* Total values:
  + Total values (1): 106.23 ms (FDD, 30 kHz)
  + Total values (2): 667.87 ms (FDD, 60 kHz)
  + Total values (3): 107.63 ms (TDD, 30 kHz)
  + Total values (4): 668.60 ms (TDD, 60 kHz)
* Case 2:
  + Start trigger:
    - Transmission of the PDSCH from the gNB carrying the LPP Request Location Information
  + End trigger:
    - Calculation of Location Estimate at the UE
  + Difference from UE-assisted method:
    - Update the start and end triggers accordingly
    - Step 8 should be removed since UE is the location consumer, which is replaced by “UE location calculation” (assume the latency is [1 slot])
  + Total values:
    - Total values (1): 106.30 ms (FDD, 30 kHz)
    - Total values (2): 667.82 ms (FDD, 60 kHz)
    - Total values (3): 107.08 ms (TDD, 30 kHz)
    - Total values (4): 668.51 ms (TDD, 60 kHz)
* Case 3:
  + Start trigger:
    - Transmission of the PDSCH from the gNB carrying the LPP message containing the assistance data
  + End trigger:
    - Successful decoding of the PUSCH at gNB carrying the LPP Provide Location Information message
  + Difference from UE-assisted method:
    - Update the start and end triggers accordingly.
    - Step 2 is replaced by “UE decodes and applies the LPP message containing the assistance data”.
    - Another step for “UE location calculation” (assume the latency is [1 slot]) is added between step 7 and step 8
  + Total values:
    - Total values (1): 106.23 ms (FDD, 30 kHz)
    - Total values (2): 667.87 ms (FDD, 60 kHz)
    - Total values (3): 107.63 ms (TDD, 30 kHz)
    - Total values (4): 668.60 ms (TDD, 60 kHz)
* Case 4:
  + Start trigger:
    - Transmission of the PDSCH from the gNB carrying the LPP message containing the assistance data
  + End trigger:
    - Calculation of Location Estimate at the UE
  + Difference from UE-assisted method:
    - Update the start and end triggers accordingly
    - Step 2 is replaced by “UE decodes and applies the LPP message containing the assistance data”
    - Step 8 should be removed since UE is the location consumer, which is replaced by “UE location calculation” (assume the latency is [1 slot])
  + Total values:
    - Total values (1): 106.30 ms (FDD, 30 kHz)
    - Total values (2): 667.82 ms (FDD, 60 kHz)
    - Total values (3): 107.08 ms (TDD, 30 kHz)
    - Total values (4): 668.51 ms (TDD, 60 kHz)

*UE-assisted positioning method based on DL-ECID*

* Assumptions:
  + Source [UE]/Destination [NW]
  + Positioning technique [DL-ECID], type [DL], mode [UE-A],
  + Initial and Final RRC States [CONNECTED]
* Components:
  + Start trigger
  + UE interprets and applies the measurement configuration: 10 ms
  + UE ECID measurement time:
  + UE positioning measurement transmission:
    - UL user plane latency for NR FDD with grant free transmission:
      * 30 kHz: 0.43 ms
      * 60 kHz: 0.30 ms
    - UL user plane latency for NR TDD with grant free transmission:
      * 30 kHz: 1.09 ms
      * 60 kHz: 0.64 ms
  + End trigger
* Total values:
  + FDD and 30KHz SCS:
    - RRM measurement is available: 10.43 ms
    - RRM measurement is not available (without associated SSB index): 410.43 ms
    - RRM measurement is not available (with associated SSB index): 470.43 ms
  + FDD and 60KHz SCS:
    - RRM measurement is available: 10.30 ms
    - RRM measurement is not available (without associated SSB index): 510.43 ms
    - RRM measurement is not available (with associated SSB index): 570.43 ms
  + TDD and 30KHz SCS:
    - RRM measurement is available: 11.09 ms
    - RRM measurement is not available (without associated SSB index): 411.09 ms
    - RRM measurement is not available (with associated SSB index): 471.09 ms
  + TDD and 60KHz SCS:
    - RRM measurement is available: 10.64 ms
    - RRM measurement is not available (without associated SSB index): 510.64 ms
    - RRM measurement is not available (with associated SSB index): 570.64 ms

Observations:

* The dominant contributors of physical layer latency for DL-TDOA method are UE positioning measurement and MG request procedures
* TDD or FDD configuration is not the dominant contributor on physical layer latency
* UE requires additional time for beam sweeping (or beam alignment) in FR2, which leads to much higher physical layer latency over FR1
* Based on Rel-16 positioning procedures, DL-TDOA method is hard to meet stringent physical layer latency requirements in Rel-17
* DL-ECID method consumes small physical layer latency if RRM measurement is available at UE side

## Source #4

In [[4], CATT], the evaluation of Rel.16 positioning methods and the Rel.17 potential enhancements are provided. The positioning accuracy, physical layer latency, and network efficiency are analysed. The evaluations are performed in FR1 and FR2 frequency bands.

The following set of scenarios is considered:

* InF-SH-2D, InF-DH-2D, InF-SH-3D, InF-DH-3D, IOO
* With and without UE/gNB calibration errors
* With and without network synchronization errors

The following positioning techniques are evaluated:

* FR1 band:
  + DL-TDOA, UL-TDOA, Multi-RTT, DL-AOD, UL-TDOA + UL-AOA
* FR2 band:
  + DL-TDOA, UL-TDOA, Multi-RTT, DL-AOD, UL-TDOA + UL-AOA

**Rel.16 positioning methods evaluation**

**Accuracy**

Observations:

* Without considering the network synchronization error and UE/gNB Tx/Rx calibration error, Rel-16 NR positioning techniques can meet the commercial use case (IOO) horizontal accuracy performance requirements [1]m @[90]%, and IIoT use cases (InF-SH and InF-DH) horizontal accuracy performance requirements [0.5]m @[90]%, but cannot meet IIoT use cases (InF-SH and InF-DH) horizontal accuracy performance requirements [0.2]m @[90]%.
* Without considering the network synchronization error and UE/gNB Tx/Rx calibration error, none of the simulated IIoT cases can meet the vertical accuracy performance requirement of [0.2m] @[90]%. Most of the simulated IIoT cases cannot meet the vertical accuracy performance requirements of [1m] @[90]%.
* Network synchronization error and UE/gNB Tx/Rx calibration error have great impact on Rel-16 NR positioning accuracy performance.

**Physical layer latency**

*Latency analysis for DL-TDOA method*

* Components (in general):
  + Tgap,req denotes the time to require measurement gap, which is 1ms according to the result of URLLC latency in TR 38.824
  + Tgap,cfg denotes the time for measurement gap configuration, which could be assumed as 10ms according to RRC reconfiguration procedure delay in TS 38.331
  + Tariv denotes the delay between the time when DL PRS is received and the time when measurement gap configuration is received, which is related to the maximum value of the configured periodicity of PRS and measurement gap
  + Tprocess denotes the time from UE begins to measure PRS until the measurement result is ready to report. T\_processis related to UE capability and the number of PRS resources needed to be measured
  + Treport denotes the time for measurement reporting, which includes SR request, PDCCH-based UL grant and PUSCH-based measurement result reporting
* 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
* Components (for DL-TDOA, calculation):
  + Start trigger: 1 ms
  + Measurement gap configuration: 10 ms
  + PRS arrival delay: ≤ 20 ms
  + Process time: ≤ 20 ms
  + End trigger: 0.5 ms
* Total values: ≤ 51.5 ms

*Latnecy analysis for UL-TDOA method*

* Components (in general):
  + TSRS,act denotes the time to activate the SRS transmission.
  + Tprep denotes the delay from effective time of SRS activation until UE begins to transmit SRS, which is related to the value of the configured periodicity of SRS.
  + Tprocess denotes the time from gNB begins to measure SRS until the measurement result is ready, which is related to UE capability and the number of SRS resources needed to be measured.
* 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
* Components:
  + Start trigger: 3 ms
  + UL SRS arrival delay: ≤ 1 ms
  + End trigger: ≤ 1 ms
* Total values: ≤ 5 ms

Observations:

* Physical layer latency for DL positioning needs to be significantly reduced in R17 to meet the 10ms requirement

**Rel.17 potential enhancements**

**Accuracy**

* Scenarios:
  + InF-HH-2D
  + FR1 band
  + DL-TDOA +DL-CPP, UL-TDOA + UL-CPP

Observations:

* CPP (DL-TDOA + DL-CPP, and UL-TDOA + UL-CPP) with double differential techniques can meet the IIoT (InF-HH-2D) horizontal accuracy performance requirements [0.2]m@[90]% even when the network synchronization error is simulated

**Physical layer latency**

* Assumptions (in general):
  + Case ID: 1.
  + SCS: 15kHz.
  + Frequency Band: FR1.
  + Positioning Technique: DL-TDOA [R1-2007860].
  + Periodicity of PRS: Aperiodic PRS
  + Duration time of PRS: 4ms
* Components (in general):
  + Ttrig denotes the time to receive and decode the A-PRS triggering signalling.
  + Tariv denotes the delay when DL PRS is received, which is related to the PRS offset value configured by the A-PRS triggering signalling
  + Tprocess denotes the time from UE begins to measure PRS until the measurement result is ready, which is related to UE capability and the number of PRS resources needed to be measured.
  + Treport denotes the time for measurement reporting, which includes SR request, PDCCH-based UL grant and PUSCH-based measurement result reporting
* 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
* Components:
  + Start trigger: 1 ms
  + PRS arrival delay: 4 ms
  + Process time: ≤ 8 ms
  + End trigger: 0.5 ms
* Total values: ≤ 13. 5 ms

Observations:

* For the case 1, 15 kHz, FR1, DL-TDOA:
  + Commercial requirements [100]ms are met: Yes
  + IIoT requirements of [10]ms are met: No (3.5ms gap)
  + IIoT requirements of [100]ms are met: Yes

**Network efficiency analysis**

Observations:

* NR positioning enhancements with carrier phase measurements has no impact on UE and network RF resource usage efficiency

## Source #5

In [[5], FUTUREWEI], the evaluation of Rel.16 positioning methods and the Rel.17 potential enhancements are provided. The positioning accuracy is are analysed. The evaluations are performed in FR1 frequency band.

The following set of scenarios is considered:

* InF-SH/InF-DH baseline scenarios, no UE/gNB calibration error
* InF-DH, variable UE/gNB heights:
  + Baseline: gNB (8 m) and UE (1.5 m)
  + Additional gNB heights: 6 gNBs (4 m) and 12 gNBs (8 m)

**Rel.17 enhancements**

*LOS/NLOS classification*

Assumptions/methods:

* Baseline: no LOS detection
* Polarization LOS detection: angle-based
* Polarization LOS detection: power-based
* Polarization LOS detection: combined, i.e. angle-based + power-based
* Polarization LOS detection: single polarized UE receiver

Observations:

* LOS (or NLOS) detection provides a robust method to improve the positioning accuracy. The gains that can be obtained vary dependent on channel condition specifically the number of LOS (or NLOS) links in the channel.
* LOS (or NLOS) identification based on detection of the transmitted PRSs polarization is shown to be feasible and can identify and reduce the probability of selecting a NLOS link as one of the selected paths for the positioning estimation calculation.

Proposals:

* Reception of PRSs with different polarizations is shown to be feasible and should be supported as an approach for the LOS/NLOS identification.

## Source #6

In [[6], Lenovo, Motorola Mobility], the evaluation of the physical layer latency for Rel.16 NR positioning is provided. The evaluations are performed in FR1 and FR2 frequency bands.

The following positioning techniques are evaluated:

* FR1 band:
  + DL-TDOA, DL-AOD
* FR2 band:
  + DL-TDOA, DL-AOD

**Physical layer latency**

Assumptions:

* Similar physical layer latency components are expected for DL-TDOA and DL-AoD methods, and are therefore jointly analyzed.
* The range of latency values was defined in terms of a minimum value, which are based on the aggressive UE capability 2 (URLLC) UE with readily available UL resources, while a cautious estimate may follow relaxed requirement (capability 1) UE using SR-based scheduling for UL resources.
* The UEs start and final states are selected to be in the RRC\_CONNECTED with the assumption that the UE has exchanged prior LPP messages such as capability and assistance data. Any potential RACH latencies for initial access and state transitional delays for performing measurements and reporting are not within the scope of the provided positioning latency evaluations.
* The physical layer latency analysis for each of the scenarios in Tables 1-4 includes two SCS values including 30 kHz and 120 kHz applicable to FR1 and FR2.
* The PUSCH preparation time for transmitting the required RRC/LPP message is based on ITU definition [3] of UP latency which is “the one-way time taken to successfully deliver an application layer packet/message from the radio protocol layer 2/3 SDU ingress point to the radio protocol layer 2/3 SDU egress point of the radio interface in either uplink or downlink.”.
* For simplicity of the evaluation, the number of DL-PRS occasions (NOcc) is set to 1, although this may not be representative of the required accuracy for the positioning measurements, which in turn affects the location accuracy.

*UE-assisted physical layer latency for DL-TDOA/DL-AOD with MG configuration*

* Assumptions
  + Case ID: 1, Scenario: All, UE-Assisted Positioning with MG configuration, Frequency Band: FR1/FR2, Technique: R.16 DL-TDOA or R.16 DL-AoD
  + Positioning technique(s): DL-TDOA or DL-AoD, Type: DL, Mode: UE-Assisted (UE-A)
  + Initial RRC State CONNECTED, Final RRC State CONNECTED
* Components:
  + Start trigger (Air Interface1 Latency) Source: NW, Destination: UE: FR1 band (min/cautious value 1 ms / 2 ms), FR2 band (min/cautious value 0.25 ms / 0.5 ms)
  + UE Processing4 of LPP Request Location Information message: 3 ms / 10 ms
  + UL Transmission of Measurement Gap Request (SR-based Scheduling): 1 ms / 3.8 ms
  + Measurement Gap Request (Air Interface Latency1) Source: UE, Destination: NW: FR1 band (min/cautious value 1 ms / 2 ms), FR2 band (min/cautious value 0.25 ms / 0.5 ms)
  + gNB Processing3 of Measurement Gap Request: 3 ms / 10 ms
  + Measurement Gap Configuration (Air Interface1 Latency) Source: NW, Destination: UE: FR1 band (min/cautious value 1 ms / 2 ms), FR2 band (min/cautious value 0.25 ms / 0.5 ms)
  + UE Processing4 of Measurement Gap Configuration message: 3 ms / 10 ms
  + MG Gap Repetition Period (TMGRP), NOcc= 1: 1×20 ms / 1×160 ms
  + UE Processing of DL-PRS Units (NProc,T) in addition to the TMGRP: (NProc,T) = (6,8) 0 ms / (NProc,T) = (20,160) 20 ms
  + UL Transmission of Measurement Report without UL grant: 1 ms / 3.8 ms
  + End Trigger (Air Interface1 Latency) Source: UE, Destination: NW: FR1 band (min/cautious value 1 ms / 2 ms), FR2 band (min/cautious value 0.25 ms / 0.5 ms)
  + End Trigger: 3 ms / 10 ms
* Total values: FR1 band (min/cautious value 38 ms / 235.6 ms), FR2 band (min/cautious value 35 ms / 229.6 ms)

*UE-assisted physical layer latency for DL-TDOA/DL-AOD without MG configuration*

* Total values: FR1 band (min/cautious value 17 ms / 5147.8 ms), FR2 band (min/cautious value 15.5 ms / 5144.8 ms)

*UE-based physical layer latency for DL-TDOA/DL-AOD with MG configuration*

* Total values (with request to provide location information message): FR1 band (min/cautious value 29 ms / 207.8 ms), FR2 band (min/cautious value 27.5 ms / 204.8 ms)
* Total values (without request to provide location information message): FR1 band (min/cautious value 38 ms / 265.6 ms), FR2 band (min/cautious value 35 ms / 259.6 ms)

*UE-based physical layer latency for DL-TDOA/DL-AOD without MG configuration*

* Total values (with request to provide location information message): FR1 band (min/cautious value 17 ms / 5147.8 ms), FR2 band (min/cautious value 15.5 ms / 5144.8 ms)

Observations:

* The physical latency evaluations do not consider positioning measurement errors/radio failure events and delays induced through UE assistance data configurations

A remaining open issue from the previous RAN#102-e meeting, is to down select the start time for UE-based positioning methods from the following alternatives:

* 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

Proposals:

* Select Alt. 1 as the proposed start time of physical layer evaluations for UE-based positioning methods

Observations:

* In the case of the minimum estimated total physical layer latency for DL-TDOA/DL-AoD positioning, the commercial and IIoT physical layer latency requirements of <100ms may/may not be met across the scenarios, subject to the higher-layer latency evaluations.
* In the case of the minimum estimated total physical layer latency for DL-TDOA/DL-AoD positioning, the stringent commercial and IIoT latency requirements of <10ms cannot be largely met across the scenarios (except for Case ID: 4) even though the higher-latency evaluations are not part of the scope.
* In the case of the cautious estimated total physical layer latency for DL-TDOA/DL-AoD positioning, the stringent commercial and IIoT requirements of <100 ms and <10 ms cannot be met across the scenarios even though the higher-latency evaluations are not part of the scope.
* The balance between accurate measurements and physical layer latency needs to be carefully considered in terms of:
  + UE Processing of the Provide Location Information Request
  + UE and gNB processing of MG request and configurations
  + DL-PRS Periodicity and Number of DL-PRS occasions for accurate positioning measurements
  + UE processing of DL-PRS
  + Availability of UL grants for transmission of measurement report.

Proposals:

* In order to address the latency bottlenecks, the physical layer latency reduction techniques can be considered for:
  + Enhancements related to the UE processing of DL-PRS for both UE-assisted and UE-based positioning techniques.
  + Lower layer procedures that enable low latency measurement reporting for UE-assisted positioning techniques.

## Source #7

In [[7], OPPO], the evaluation of Rel.16 positioning methods and the Rel.17 potential enhancements are provided. The positioning accuracy and physical layer latency are analysed. The evaluations are performed in FR1 and FR2 frequency bands.

The following set of scenarios is considered:

* InF-SH/InF-DH baseline scenarios, different parameter D = 20 m, 50 m

The following positioning techniques are evaluated:

* DL-TDOA

**Rel.16 positioning methods evaluation**

**Accuracy**

Observations:

* The performance of DL-TDOA in InF scenarios are:
  + In InF-SH scenario, < 1m accuracy for 90% of UEs is achievable.
  + In InF-DH scenarios, < 1m accuracy for 90% of UEs is not achievable.
    - D = 20m can achieve 2.47 m accuracy for 90% of UEs.
    - D = 50m can achieve 13.19m accuracy for 90% of UEs.

**Rel.17 potential enhancements**

*Multipath mitigation*

Methods for NLOS mitigation:

* The method of LOS classification: LOS/NLOS channel are estimated, the decision of LOS/NLOS is the estimated K factor larger than 0 dB in simulation
* The method of NLOS mitigation: RSTD are pruned by implementation, the quality of RSTD are verified by triangle inequality in simulation

Reference performance:

* ALL TRP: RSTD of all the TRPs are used for positioning calculation, which can be considered as the worst case for NLOS
* LOS classification (perfect): here we assume we know the LOS/NLOS perfectly for positioning

Observations:

* Implementing NLOS mitigation can improve positioning accuracy
* Implementing LOS classification method can improve the positioning accuracy, but the errors in LOS classification may decrease performance
* In InF-SH scenario, gain from the method of LOS classification is marginal

**Physical layer latency**

*UE-assisted DL-based method*

* Assumptions:
  + The system sends LRR location request information, that is the trigger time.
  + After the UE receives the LRR location request information, the UE sends RRC location indication message to request configuration of measurement gap.
  + To respond the UE, the gNB configures measurement gap for the UE to measure DL PRS resources.
  + Based on the configuration, the UE receives the DL PRS resource during measurement gap and then conduct the required measurement, such as RSTD or RSRP.
  + After the positioning measurement is ready, the UE sends SR to request uplink grant, the gNB schedule PUSCH grant and then the UE reports the positioning measurement through PUSCH grant.
  + Finally, the gNB decode the PUSCH carrying the positioning measurement.
* Components:
  + Start trigger: gNB sending PDSCH carrying LPP location request message
  + UE process LPP location request information message: 10 ms
  + UE requests MG and gNB configures MG: 10 ms + 10 ms
  + DL PRS reception and measurement: minimum value is 20ms + 1ms
  + UE sends PUSCH carrying location measurement report and gNB decode PUSCH:
    - 12.5ms for 15KHz
    - 6.25ms for 30KHz
    - 3.125ms for 60KHz
    - 1.56 ms for 120KHz
* Total values:
  + FR1 band, 60 kHz: 54.125ms
  + FR2 band, 120 kHz: 52.56 ms

*UE-assisted UL-based method*

* Assumptions:
  + The gNB receives NPPPa measurement request from the NW, that is treated as the start time of this procedure
  + The gNB sends the configuration of SRS for positioning.
  + If the SRS is semi-persistent or aperiodic, the gNB sends MAC CE or DCI to activate or trigger the transmission of SRS for positioning. This step is optional for latency analysis.
  + Then the UE transmits the SRS for positioning according to the configuration
  + The gNB receives the SRS for positioning and conduct corresponding measurement.
  + Finally, the gNB reports the uplink measurement results to the server.
* Components:
  + Start trigger: gNB receives NPPPa measurement request
  + gNB process the NPPPa measurement request: 10 ms
  + gNB configures SRS: 10 ms
  + UE transmits SRS for positioning:
    - 1ms for 15KHz
    - 0.25ms for 60KHz.
    - 0.125ms for 120KHz
  + gNB measures SRS for positioning and reports the NPPPa measurement response: 3 ms
* Total values:
  + FR1 band, 60 kHz: 23.25ms
  + FR2 band, 120 kHz: 23.125ms

*UE-based methods*

* Assumptions:
  + The UE sends LPP request assistance data message to request the configuration of DL PRS from the NW. And the NW configures the DL PRS resource by sending the LPP provide assistance data. In our view, we do not need count this step in the physical layer latency calculation because the configuration of DL PRS is semi-static and the UE only requests it once.
  + For receiving and measuring DL PRS, the UE needs measurement gap. The UE sends RRC location measurement location to the gNB to request configuration of measurement gap.
  + The gNB responds to the UE and sends the RRC configuration of measurement gap.
  + Within the measurement gap, the UE receives the DL PRS and then conducts corresponding measurement.
  + Finally, the UE calculates the location.
* Components:
  + Start trigger: UE sends RRC Location measurement indication: 10 ms
  + gNB sends RRC measurement gap configuration: 10 ms
  + DL PRS reception and measurement: minimum value 20 ms + 1 ms
  + UE completes location calculation: 3 ms
* Total values: 44 ms

Observations:

* For UE-assisted DL-based method, the total latency is 54.125ms for FR1 (60KHz), 52.56ms for FR2 (120KHz);
* For UE-assisted UL-based method, the total latency is 23.25ms for FR1 (60KHz SCS), 23.125ms for FR2 (120KHz);
* For UE-based method, the total latency is 44ms

## Source #8

In [[8], Nokia, Nokia Shanghai Bell], the evaluation of Rel.16 positioning methods is provided. The positioning accuracy and physical layer latency are analysed. The evaluations are performed in FR1 frequency band.

The following set of scenarios is considered:

* InF-SH/InF-DH baseline scenarios
* UMi/IOO additional scenarios

The following positioning techniques are evaluated:

* FR1 band:
  + DL-TDOA, UL-TDOA

**Accuracy**

Observations:

* The performance of DL-TDOA is significantly worse in InF-DH compared with InF-SH. Meeting the strictest accuracy requirements for InF-DH may be challenging.
* The performance of DL-TDOA is better in the InF-SH scenario compared with IOO.
* The performance of DL-TDOA is significantly improved through the use of oversampling.
* UL-TDOA results show similar performance trends to the DL-TDOA results for InF scenarios.
* LoS detection and outlier rejection are able to improve the achievable accuracy in UL-TDOA.

**Physical layer latency analysis**

*DL-TDOA, type: DL, mode: UE-A*

* Assumptions:
  + Source: NW/Destination: NW
  + Positioning technique: DL-TDOA, type: DL, mode: UE-A
  + Initial and Final RRC States: Initial/Final – CONNECTED
* Components:
  + Start trigger
  + Processing of PDSCH: [3-24 symbols]
  + Transmission of DL PRS: [4-10240 slots]
  + Processing of DL PRS at UE: [8-1280 ms]
  + Transmit SR: [2 symbols – 1640 slots]
  + Processing of SR at gNB: [1 symbol]
  + UL grant preparation and transmission of UL grant by gNB: [3 symbols ]
  + UE processing of PDCCH and UL preparation: [5-36 symbols]
  + Scheduling delay - K2: [0-32 slots]
  + gNB processing of RSTD Report: [1-2 symbol]
  + End trigger
* Total values:
  + [13.07 – 2956.71] ms (15 kHz SCS)

Observations:

* If 10 ms overall latency is required for positioning, then the latency budget for PHY layer alone is already too large and the requirement would not be met.
* The DL PRS processing time can be the largest contributor to the PHY layer latency and is independent of the SCS.
* The DL PRS periodicity may have a large impact on the PHY layer latency.
* Some components of the PHY latency (e.g., SR occasion) depend on gNB configuration of the UE.

Proposals:

* Solutions to enhance the PHY latency for positioning at least for DL methods will be investigated.

*UL-TDOA, type: UL, mode: UE-A*

* Assumptions:
  + Source: NW/Destination: NW
  + Positioning technique: UL-TDOA, type: UL, mode: UE-A
  + Initial and Final RRC States: Initial/Final – CONNECTED
* Components:
  + Start trigger
  + Wait for transmission of SRS-Pos: [1-81920 slots]
  + Transmission of SRS-Pos: [2 symbols- 8 symbols]
  + Processing of SRS-Pos at gNB/RP-only: [1-5 slots]
  + Preparation of UL measurement report: [3 symbols ]
  + End trigger
* Total values: [2.35 – 81925] ms (15 kHz SCS)

Observations:

* PHY latency in UL-TDOA is lower than DL-TDOA but relies on SRS-Pos already being configured (e.g., higher layer latency takes this into account, see RAN2 analysis).
* PHY latency in UL-TDOA is also heavily dependent on SRS-Pos periodicity. Therefore, low latency will require high overhead unless considering non-periodic SRS which also had additional delay components.

## Source #9

In [[9], Sony], the evaluation of Rel.16 positioning methods and the Rel.17 potential enhancements are provided. The positioning accuracy and physical layer latency are analysed. The evaluations are performed in FR1 and FR2 frequency bands.

The following set of scenarios is considered:

* InF-SH/InF-DH baseline scenarios
* InH-OO (IOO) scenario

The following positioning techniques are evaluated:

* FR1 band:
  + DL-TDOA
  + DL-TDOA + DL-AOD + NLOS, DL-TDOA + NLOS, DL-TDOA + DL-AOD
* FR2 band:
  + DL-TDOA
  + DL-TDOA + DL-AOD + NLOS, DL-TDOA + NLOS, DL-TDOA + DL-AOD

**Rel.16 positioning methods evaluation**

**Accuracy**

Observations:

* Performance of Rel.16 NR positioning techniques meet the commercial horizontal accuracy requirements in InF-SH and InH-OO scenarios in both DL FR1 and FR2 cases. The performance in InF-DH is relatively worse than the former two scenarios.
* By using Rel.16 NR positioning techniques, none of these scenarios can achieve the IIoT requirements of 0.2 m horizontal accuracy at 90% of the UE.

**Rel.17 potential enhancements**

Methods:

* NLOS mitigation technique

Observations (Horizontal accuracy of Rel.17 NR positioning):

* The IIoT horizontal requirement (< 0.2 m accuracy @ 90% CDF) can be achieved in InF-SH FR2 scenario.
* In 3 scenarios, InF-SH FR2, InF-SH FR1 and InH-OO FR2, the IIoT, the achievable accuracy is < 0.5 m at 90% CDF.
* The enhancement of NLOS detection algorithm from Rel.16 to Rel.17 improves the horizontal positioning accuracy, especially in InF-DH scenario. The improvement can be up to 1.7 m in InF-DH FR1 case.

Observations (Vertical accuracy of Rel.17 NR positioning):

* The commercial requirements (< 3 m accuracy) can be fulfilled in all scenarios under evaluation.
* The performance gap between two IIoT requirement and the simulation results are still very large. None of the cases with default gNB height can achieve the IIoT requirement.
* In one of gNB height deployment configuration (Case 7) and in InF-SH FR2 scenario, the achievable performance is less than 1 m accuracy.

Study:

* Investigation of gNB height on vertical positioning accuracy

Observations (impact of gNB height):

* The vertical positioning becomes more accurate as the gNB height are getting diverse. In other word, using gNBs with different height can improve the vertical positioning accuracy.
* In the deployment 3 to 5 and in InF-SH FR2 scenario, the achievable performance is less than 1 m accuracy.

Study:

* Bandwidth impact on positioning accuracy

Observations:

* The usage of PRS configuration in a smaller bandwidth degrades the positioning accuracy performance. In the other word, by changing the bandwidth, we can control the positioning accuracy.

**Physical layer latency**

*Physical layer latency for DL-TDOA in legacy NR Rel.16*

* Components:
  + LMF send Location request to UE: 10 ms
  + UE request/receive and wait for a configured measurement gap: 11 ms
  + UE measures the PRS: 22.5 ms
  + UE request to send and send a measurement report: 12.5 ms
* Total values: 56 ms

Observations:

* Rel.16 physical layer latency for DL PRS based positioning is estimated to be more than 56 ms. Approximately, 60 % of the physical layer latency is for signaling and 40 % is for measuring and handling of measurement gap.
* A significant modification to the existing procedure is required in order to achieve 10ms physical layer latency. This may include shortening the existing signaling / measurement and removing some of the signaling.

## Source #10

In [[10], LG Electronics], the evaluation of physical layer latency is provided.

The following positioning techniques are evaluated:

* DL-TDOA, DL-AOD, UL-TDOA, UL-AOA, Multi-RTT, E-CID

**Physical layer latency**

*DL-TDOA/DL-AOD*

* Assumptions:
  + Source/Destination: NW/UE
  + Positioning technique DL-TDOA and DL-AOD, mode: UE-A/UE-B
  + Initial and Final RRC States: CONNECTED
* Components:
  + Request Location Information message (gNB to UE): 0.14 ms ~ 1 ms
  + Request Location Information message Reception (PHY Processing time for PDSCH, UE):
    - For UE capability-1: 0.57 ms ~ 0.78 ms
    - For UE capability-2: 0.21 ms
  + \*Transportation of Request Location Information message (RRC processing time, UE): 10 ms
  + \*Constructing measurement gap request message (RRC processing time, UE): 10 ms
  + Measurement gap request (including PHY preparation time for PUSCH, UE):
    - For UE capability-1: 0.85 ms ~ 1.78 ms
    - For UE capability-2: 0.49 ms ~ 1.42 ms
  + \*Reception of measurement gap request and preparation time for measurement gap(gNB): X1 - is up to gNB processing capability and it can vary depending on LS’s response from higher layer
  + \*Transportation of Measurement gap request message (RRC processing time, UE): 10 ms
  + \*Constructing measurement gap configuration message(RRC processing time, gNB): 10 ms
  + Measurement gap configuration message (gNB to UE): 0.14 ms ~ 1 ms
  + Measurement gap configuration message reception (PHY Processing time for PDSCH, UE):
    - For UE capability-1: 0.57 ms ~ 0.78 ms
    - For UE capability-2: 0.21 ms
  + PRS measurement within measurement gap (UE): 20ms ~ 160ms
  + \*Constructing Provide Location information message(RRC processing time, UE): 10 ms
  + Transmission of measurement report (including PHY preparation time for PUSCH, UE):
    - For UE capability-1: 0.85 ms ~ 1.78 ms
    - For UE capability-2: 0.49 ms ~ 1.42 ms
  + \*Reception of measurement report and preparation time for gNB to make NRPPa message (gNB): X2 - is up to gNB processing capability and it can vary depending on LS’s response from higher layer
* Total values:
  + When procedure marked with(\*) is not excluded:
    - For UE capability-1: 73.12+[X1]+[X2]ms ~ 217.12+[X1]+ [X2]ms
    - For UE capability-2: 71.68+[X1]+[X2]ms ~ 215.26+[X1]+ [X2]ms
  + When procedure marked with(\*) is excluded, total values shall be amended as follows:
    - For UE capability-1: 23.12ms ~ 167.12ms
    - For UE capability-2: 21.68ms ~ 165.26ms

NOTE: Some components denoted by (\*) can be excluded since they are related with higher layer procedure.

* Assumptions:
  + Source/Destination: UE/NW
  + Positioning technique DL-TDOA, mode: UE-A/UE-B
  + Initial and Final RRC States: CONNECTED
* Total values:
  + When procedure marked with(\*) is not excluded:
    - For UE capability-1: 62.41+[X1]+[X2]ms ~ 205.34+[X1] +[X2]ms
    - For UE capability-2: 61.33+[X1]+[X2]ms ~ 204.05+[X1] +[X2]ms
  + When procedure marked with(\*) is excluded, total values shall be amended as follows:
    - For UE capability-1: 22.41ms ~ 165.34ms
    - For UE capability-2: 22.33ms ~ 164.05ms

*UL-TDOA/UL-AOA*

* Assumptions:
  + Source/Destination: NW/UE
  + Positioning technique UL-TDOA and UL-AOA, mode: -
  + Initial and Final RRC States: CONNECTED
* Components:
  + SRS configuration (gNB to UE): 0.14 ms ~ 1 ms
  + Reception of SRS configuration (PHY Processing time for PDSCH, UE):
    - For UE capability-1: 0.57 ms ~ 0.78 ms
    - For UE capability-2: 0.21 ms
  + \*Transportation of SRS configuration message (RRC processing time, UE): 10 ms
  + \*Transportation of SRS activation message (RRC processing time, gNB): 10 ms
  + Transmission of SRS activation (gNB to UE): 0.14 ms ~ 1 ms
  + Reception of SRS activation (PHY Processing time for PDSCH, UE):
    - For UE capability-1: 0.57 ms ~ 0.78 ms
    - For UE capability-2: 0.21 ms
  + \*Transportation of SRS activation message (RRC processing time, UE): 10 ms
  + SRS transmission (UE): 0.07ms ~ 0.86ms
  + \*Reception of SRS and preparation time for gNB to make NRPPa message (gNB): X3 - is up to gNB processing capability and it can vary depending on LS’s response from higher layer
* Total values:
  + When procedure marked with(\*) is not excluded:
    - For UE capability-1: 1.49ms ~ 4.42ms
    - For UE capability-2: 0.77ms ~ 3.28ms
  + When procedure marked with(\*) is excluded, total values shall be amended as follows:
    - For UE capability-1: 31.49+[X3] ms ~ 34.42+[X3] ms
    - For UE capability-2: 30.77+[X3] ms ~ 33.28+[X3] ms

*Multi-RTT*

* Assumptions:
  + Source/Destination: NW/UE
  + Positioning technique: Multi-RTT, mode: UE-A
  + Initial and Final RRC States: CONNECTED
* Components:
  + SRS configuration (gNB to UE): 0.14 ms ~ 1 ms
  + Reception of SRS configuration (PHY Processing time for PDSCH, UE):
    - For UE capability-1: 0.57 ms ~ 0.78 ms
    - For UE capability-2: 0.21 ms
  + \*Transportation of SRS configuration message (RRC processing time, UE): 10 ms
  + \*Transportation of SRS activation message (RRC processing time, gNB): 10 ms
  + Transmission of SRS activation (gNB to UE): 0.14 ms ~ 1 ms
  + Reception of SRS activation (PHY Processing time for PDSCH, UE):
    - For UE capability-1: 0.57 ms ~ 0.78 ms
    - For UE capability-2: 0.21 ms
  + \*Transportation of SRS activation message (RRC processing time, UE): 10 ms
  + \*Transportation of provide assistance message (RRC processing time, gNB): 10 ms
  + Transmission of LPP provide assistance data (gNB to UE): 0.14 ms ~ 1 ms
  + Reception of LPP provide assistance data (PHY Processing time for PDSCH, UE):
    - For UE capability-1: 0.57 ms ~ 0.78 ms
    - For UE capability-2: 0.21 ms
  + \*Transportation of provide assistance message (RRC processing time, UE): 10 ms
  + \*Transportation of request location information (RRC processing time, gNB): 10 ms
  + Request Location Information message (gNB to UE): 0.14 ms ~ 1 ms
  + Location Information message Reception (PHY processing time for PDSCH, UE):
    - For UE capability-1: 0.57 ms ~ 0.78 ms
    - For UE capability-2: 0.21 ms
  + \*Transportation of LPP message (RRC processing time, UE): 10 ms
  + \*Transportation of measurement gap request (RRC processing time, UE): 10 ms
  + Measurement gap request (including PHY preparation time for PUSCH, UE):
    - For UE capability-1: 0.85 ms ~ 1.78 ms
    - For UE capability-2: 0.49 ms ~ 1.42 ms
  + \*Reception of measurement gap request and preparation time for measurement gap(gNB): X1 - is up to gNB processing capability and it can vary depending on LS’s response from higher layer
  + \*Transportation of measurement gap request message (RRC processing time, gNB): 10 ms
  + \*Constructing measurement gap configuration message(RRC processing time, gNB): 10 ms
  + Measurement gap configuration message: 0.14 ms ~ 1 ms
  + Measurement gap configuration message reception (PHY Processing time for PDSCH, UE):
    - For UE capability-1: 0.57 ms ~ 0.78 ms
    - For UE capability-2: 0.21 ms
  + \*Transportation of Measurement gap configuration message (RRC processing time, UE): 10 ms
  + PRS measurement within measurement gap (UE): 20ms ~ 160ms
  + SRS transmission (UE): 0.07ms ~ 0.86ms
  + \*Reception of SRS and preparation time for gNB to make NRPPa message (gNB): X3 - is up to gNB processing capability and it can vary depending on LS’s response from higher layer
  + \*Constructing Provide Location information message(RRC processing time, UE): 10 ms
  + Measurement report transmission(including PHY preparation time for PUSCH, UE):
    - For UE capability-1: 0.85 ms ~ 1.78 ms
    - For UE capability-2: 0.49 ms ~ 1.42 ms
  + \*Reception of measurement report and preparation time for gNB to make NRPPa message (gNB): X2 - is up to gNB processing capability and it can vary depending on LS’s response from higher layer
* Total values:
  + When procedure marked with(\*) is not excluded:
    - For UE capability-1: 145.34+[X1]+[X2]+[X3]ms ~ 293.32+[X1]+[X2]+[X3]ms
    - For UE capability-2: 142.8+[X1]+[X2]+[X3]ms ~ 289.75+[X1]+[X2]+[X3] ms
  + When procedure marked with(\*) is excluded, total values shall be amended as follows:
    - For UE capability-1: 25.34ms ~ 173.32ms
    - For UE capability-2: 22.8ms ~169.75ms

*E-CID*

* Assumptions:
  + Source/Destination: NW/UE
  + Positioning technique: E-CID, mode: UE-A
  + Initial and Final RRC States: CONNECTED
* Components:
  + LPP Request Location Information message transmission: 0.14 ms ~ 1 ms
  + Request Location Information message Reception (PHY Processing time for PDSCH, UE):
    - For UE capability-1: 0.57 ms ~ 0.78 ms
    - For UE capability-2: 0.21 ms
  + \*Transportation of LPP Request Location Information message (RRC processing time, UE): 10 ms
  + \*Constructing Provide Location information message(RRC processing time, UE): 10 ms
  + Measurement report transmission(including PHY preparation time for PUSCH, UE):
    - For UE capability-1: 0.85 ms ~ 1.78 ms
    - For UE capability-2: 0.49 ms ~ 1.42 ms
  + \*Reception of measurement report, SRS and preparation time for gNB to make NRPPa message (gNB): X2 - is up to gNB processing capability and it can vary depending on LS’s response from higher layer
* Total values:
  + When procedure marked with(\*) is not excluded:
    - For UE capability-1: 21.56+[X2]ms ~ 23.56+[X2] ms
    - For UE capability-2: 20.84+[X2] ms~22.63+[X2] ms
  + When procedure marked with(\*) is excluded, total values shall be amended as follows:
    - For UE capability-1: 1.56ms ~ 3.56ms
    - For UE capability-2: 0.84ms~2.63ms
* Assumptions:
  + Source/Destination: UE/NW
  + Positioning technique: E-CID, mode: UE-A
  + Initial and Final RRC States: CONNECTED
* Total values:
  + When procedure marked with(\*) is not excluded:
    - For UE capability-1: 0.85+[X2] ms ~ 1.78+[X2] ms
    - For UE capability-2: 0.49+[X2] ms ~ 1.42+[X2] ms
  + When procedure marked with(\*) is excluded, total values shall be amended as follows:
    - For UE capability-1: 0.85ms ~ 1.78ms
    - For UE capability-2: 0.49ms ~ 1.42ms

*Granularity of timing report*

Proposals:

* In terms of granularity of timing report, RAN1 needs to consider higher resolution granularity and discuss about it in details in WI.

## Source #11

In [[11], InterDigital, Inc.], latency for the baseline Rel.16 is analysed and potential enhancements are provided. The evaluations are performed for the DL, UL, and DL+UL methods. For each method, UE-assisted and UE-based configurations are considered.

**Baseline latency analysis**

*DL methods*

*UE-assisted methods*

* Assumptions:
  + Source [UE, NW]/Destination [UE, NW]
  + Positioning technique: DL methods
* Components:
  + Step 1: Transmission of the PDSCH from the gNB carrying the LPP Request Location Information message: 1 ms
  + Step 2: The UE decodes the LPP Request location: 10 ms
  + Step 3: The UE transmits measurement gap (MG) request in an RRC message: 1 ms
  + Step 4: The gNB successfully decode the MG request message: 5 ms
  + Step 5: The gNB configures MG in an RRC message: 1 ms
  + Step 6: The UE receive the MG configuration message and apply the MG configuration: 10 ms
  + Step 7: The UE receives PRS in the MG: 2 ms
  + Step 8: The UE reports the positioning measurement and the gNB successful decoding of the PUSCH carrying the LPP Provide Location Information message: 3 ms
* Total values: 33 ms

*UE-based methods*

* Assumptions:
  + Source [UE, NW]/Destination [UE, NW]
  + Positioning technique: DL methods
* Components:
  + Step 1: Transmission of the PDSCH from the gNB carrying the LPP Request Location Information message: 1 ms
  + Step 2: The UE decodes the LPP Request location: 10 ms
  + Step 3: The UE transmits MG request in an RRC message: 1 ms
  + Step 4: The gNB decodes the MG request message: 5 ms
  + Step 5: The gNB configures MG in an RRC message: 1 ms
  + Step 6: The UE receive the MG configuration message and apply the MG configuration: 10 ms
  + Step 7: The UE receives PRS in the MG: 2 ms
  + Step 8: UE calculates its location: 20 - 40 ms
  + Step 9: UE reports its location: 2 ms
* Total values:
  + From Step 1 to Step 8: 50-70 ms
  + From Step 1 to Step 9: 52-72 ms
  + From Step 3 to Step 8: 39-59 ms
  + From Step 3 to Step 9: 41-61 ms
  + From Step 7 to Step 8: 22-42 ms
  + From Step 7 to Step 9: 24-44 ms

*UL methods*

*UE-assisted methods*

* Assumptions:
  + Source [UE, NW]/Destination [UE, NW]
  + Positioning technique: UL methods
* Components:
  + Reception by the gNB of the NRPPa measurement request message from LMF: NA
  + Step 1: gNB send SRS configuration via RRC: 1 ms
  + Step 2: UE decodes the RRC message including SRS configuration message: 10 ms
  + Step 3: UE transmit SRS: 1 ms
  + gNB perform measurement and transmit the NRPPa measurement response message: NA
* Total values: 12 ms

*DL+UL methods*

*UE-assisted methods*

* Assumptions:
  + Source [UE, NW]/Destination [UE, NW]
  + Positioning technique: DL+UL methods
* Components:
  + Step 1: Transmission of the PDSCH from the gNB carrying the LPP Request Location Information message: 1 ms
  + Step 2: The UE decodes the LPP Request location: 10 ms
  + Step 3: The UE transmits measurement gap (MG) request in an RRC message: 1 ms
  + Step 4: The gNB successfully decode the MG request message: 5 ms
  + Step 5: The gNB configures MG in an RRC message: 1 ms
  + Step 6: The UE receive the MG configuration message and apply the MG configuration: 10 ms
  + Step 7: The UE receives PRS in the MG: 2 ms
  + Reception by the gNB of the NRPPa measurement request message: NA
  + Step 8: The gNB send SRS configuration via RRC: 1 ms
  + Step 9: The UE decodes the RRC message including SRS configuration: 10 ms
  + Step 10: The UE transmit SRS: 1 ms
  + Step 11: The UE reports the positioning measurement and the gNB successful decoding of the PUSCH carrying the LPP Provide Location Information message: 3 ms
* Total values: 45ms

Proposals:

* Capture the PHY layer latency analysis, provided above in the TR.

**Latency enhancements analysis**

*No measurement gap for PRS reception*

* Components:
  + Step 1: Transmission of the PDSCH from the gNB carrying the LPP Request Location Information message and PRS configuration activation: 1 ms
  + Step 2: The UE decodes the LPP Request location: 10 ms
  + Step 3: The UE receives PRS without MG: 2 ms
  + Step 4: UE reports the positioning measurement and the gNB successful decoding of the PUSCH carrying the LPP Provide Location Information message 3 ms
* Total values: 16 ms

According to the above analysis, the PHY layer latency can be reduced significantly (i.e. reduce from 33ms to 16ms).

Proposals:

* Support reception of PRS without measurement gap.

*Measurement gap activation/deactivation*

* Components:
  + Step 1: Transmission of the PDSCH from the gNB carrying the LPP Request Location Information message, MG and PRS configurations: 1ms
  + Step 2: The UE decodes the LPP Request location: 10 ms
  + Step 3: The UE transmits MG activation request in an MAC CE or UCI: 1 ms
  + Step 4: The gNB successfully decodes the MG activation request: 3 ms
  + Step 5: The gNB activates the MG for the UE using MAC CE or UCI: 1 ms
  + Step 6: UE receive MG activation and apply the MG configuration: 3 ms
  + Step 7: UE receives PRS in the MG: 2 ms
  + Step 8: The UE reports the positioning measurement and the gNB successful decoding of the PUSCH carrying the LPP Provide Location Information message: 3 ms
* Total values: 24 ms

From the above analysis, using activation/deactivation of the MG can help reduce the latency several ms (i.e. reduce from 33ms to 24ms).

Proposals:

* Study activation/deactivation of MG for PRS reception using MAC CE or UCI.

*On-demand PRS*

* Components:
  + Step 1: The UE transmits measurement gap (MG) request in an RRC message: 1 ms
  + Step 2: The gNB successfully decode the MG request message: 5 ms
  + Step 3: The gNB configures MG in an RRC message: 1 ms
  + Step 4: The UE receive the MG configuration message and apply the MG configuration: 10 ms
  + Step 5: The UE receives PRS in the MG: 2 ms
  + Step 6: The UE reports the positioning measurement and the gNB successful decoding of the PUSCH carrying the LPP Provide Location Information message: 3 ms
* Total values: 22 ms

Proposals:

* Support on-demand PRS for positioning

## Source #12

In [[12], Fraunhofer IIS, Fraunhofer HHI], the evaluation of Rel.16 positioning methods and the potential enhancements are provided. The positioning accuracy is analysed. The evaluations are performed in FR1 and FR2 frequency bands.

The following set of scenarios is considered:

* InF\_LOS, InF\_NLOS\_DH

The following positioning techniques are evaluated:

* FR1 band:
  + UL-TDOA
* FR2 band:
  + UL-TDOA

**Accuracy**

*Impact of gNB antenna configuration*

Observations:

* Using antennas with higher directivity increase the performance

*Impact UE Tx Power in the presence of interference*

Observations:

* A low UE-TX power is sufficient for gNBs with beam forming in InF scenarios
* When considering interference, the performance with low TX power is only feasible if UEs sharing the same REs use different cyclic shifts for the same SRS root sequence (“cyclic shift multiplex”)

Proposals:

* For “low power operation” in combination with interference between positioning-SRS resources, cyclic shift enhancements shall be considered in Rel-17.

*Supporting “TX antenna diversity”*

Observations:

* Using TX-diversity (4 transmissions at -20dBm from different antennas) shows a similar performance as single port transmission with 0dBm.

Proposals:

* Support multi-port transmission in Rel-17.

*Uplink beam management evaluation*

*Tx-Rx Beam pair selection criteria*

Observations:

* The beam selection and spatial relationship establishment criteria have major impact on the performance.

*“Narrow” TX beams*

* When applying narrow beam antenna configuration in FR2 over multiple SRS resources, and in the presence of interference, a degradation in the positioning performance is observed. In case of several TX beams a RTOA selection/combining strategy is required. This algorithm may need further enhancements.

## Source #13

In [[13], CEWiT, IITM, Tejas Networks, IITH, Reliance Jio, Saankhya Labs], the evaluation of Rel.16 positioning methods and the Rel.17 potential enhancements are provided. The positioning accuracy is analysed. The evaluations are performed in FR1 frequency band.

The following set of scenarios is considered:

* InF-SH/InF-DH baseline scenarios

The following positioning techniques are evaluated:

* FR1 band:
  + DL-TDOA

**Accuracy**

*LOS/NLOS indication for positioning*

Observations:

* NLOS path will degrade the positioning accuracy by 5 to 10 times. So, LOS/NLOS indication is necessary for achieving sub -meter level accuracy.

Proposals:

* LOS/NLOS path indication along with power and angle reporting of corresponding path should be specified in Rel 17.

*Network synchronization error reporting*

Observations:

* Network synchronization error is critical factor in Rel 17 positioning enhancement as it degrades the positioning accuracy significantly. Synchronization correction techniques are necessary to be specified in Rel 17.

Proposals:

* PRS based network synchronization error correction techniques should be specified in Rel 17 to achieve required accuracy.

## Source #14

In [[14], Ericsson], the evaluation of Rel.16 positioning methods is provided. The positioning accuracy and physical layer latency are analysed. The evaluations are performed in FR1 and FR2 frequency bands.

The following set of scenarios is considered:

* UMa/UMi/IOO scenarios
* InF-SH/InF-DH baseline scenarios, with and without TX timing errors

The following positioning techniques are evaluated:

* FR1 band:
  + DL-TDOA, UL-TDOA
* FR2 band:
  + DL-TDOA, UL-TDOA

**Accuracy**

*Urban Macro scenario*

Observations:

* Regulatory requirement of <50 m accuracy for 80% of the UE and commercial requirement for some use cases of <10 m accuracy for 80% UE is already met in UMa scenario.
* A significant performance gap exists between the achievable and Rel. 17 target accuracies in UMa scenario.
* According to the SID the commercial use cases and requirements are applicable to a limited geographic area. Thus, we don’t see any Rel. 17 positioning use case for which UMa is applicable.

Proposals:

* Exclude UMa scenario from Rel. 17 evaluations.

*Urban Micro scenario*

Observations:

* Target accuracy of <1 m for general commercial use cases can be achieved in UMi (FR1) scenario with potential enhancements.
* With ideal beamforming, early results suggest that Rel. 17 target accuracies can be met in UMi (FR2).
* The UMi NLOS excess delay is far from negligible when targeting 1m accuracy and needs to be modelled.

Proposals:

* Include UMi scenario in Rel. 17 evaluations.
* Use the same lognormal parameters for the NLOS excess delay in UMi as the ones defined for the InF model in 38.901, i.e. log10(NLOS excess delay/1s) is normally distributed with mean mu=-7.5 and standard deviation sigma=0.4.

*Indoor Open Space scenario*

Observations:

* Target accuracy of <1 m for general commercial use cases can be achieved in IOO (FR1) scenario with potential enhancements.
* With ideal beamforming, early results suggest that Rel. 17 target accuracies can be met in IOO (FR2).
* The IOO NLOS excess delay is far from negligible when targeting 1m accuracy and needs to be modelled.

Proposals:

* Consider IOO scenario in Rel. 17 evaluations.
* Use the same lognormal parameters for the NLOS excess delay in IOO as the ones defined for the InF model in 38.901, i.e. log10(NLOS excess delay/1s) is normally distributed with mean mu=-7.5 and standard deviation sigma=0.4.

*Indoor Factory scenarios*

*FR1 results*

Observations:

* Rel. 17 target horizontal positioning accuracy of 0.2 m is met for 90% of UEs in convex hull in InF-SH scenario in FR1.
* A significant performance gap exists between the achievable and Rel. 17 target accuracy in InF-DH (FR1).

*FR2 results*

Observations:

* Rel. 17 target accuracies cannot be met in InF-DH scenario in FR2.
* Rel. 17 target accuracies are met in FR2 in InF SH scenario if there are no RX/TX timing errors but not with 8ns Rx/Tx timing errors.
* Rel. 17 target accuracies are not met in FR2 in InF DH scenario.
* Rx/Tx error affects achievable positioning accuracy.

Proposals:

* Consider Rx/Tx error for Rel. 17 evaluations.

**Physical layer latency analysis**

A DL-PRS resource can be configured with a minimum periodicity of slots. Configuring PRS resource with 9 occasions with minimum periodicity results to 33.57 ms for RS transmission time, excluding time required to transmit and receive the LPP request, measurement gaps, and measurement reports. The physical layer latency in this case is above the target latency of <10 ms as demanded by the stringent commercial use cases even without considering higher layer latency.

## Source #15

In [[15], Qualcomm Incorporated], the evaluation of Rel.16 positioning methods and the Rel.17 potential enhancements are provided. The positioning accuracy and physical layer latency are analysed. The evaluations are performed in FR1 and FR2 frequency bands.

The following set of scenarios is considered:

* InF-SH/InF-DH baseline scenarios
* UMi/UMa/InH scenarios
* InF/UMi/InH are modelled with and without timing errors

The following positioning techniques are evaluated:

* DL-TDOA, Multi-RTT, RTT + AOA

**Accuracy**

*Indoor Factory scenarios*

*FR1 results*

**FR1 horizontal accuracy performance summary**

|  |  |  |  |
| --- | --- | --- | --- |
| Simulation case  (Horizontal Error) | 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 1, InF FR1 DH ISD20, 100MHz, RANSAC, DL TDOA | 5.92 | 6.72 | 6.42 |
| Case 2, InF FR1 SH ISD50, 100MHz, RANSAC, DL TDOA | Yes | 0.08 | Yes |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Simulation case  (Horizontal Error) |  | 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 3, InF FR1 DH ISD20, 100MHz, RANSAC, DL TDOA | Variable UE heights | 11.66 | 12.46 | 12.16 |
| Fixed UE heights | 12.1 | 12.9 | 12.6 |
| Case 4, InF FR1 SH ISD50, 100MHz, RANSAC, DL TDOA | Variable UE heights | Yes | 0.02 | Yes |
| Fixed UE heights | Yes | Yes | Yes |

**FR1 vertical accuracy performance summary**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Simulation case  (Vertical Error) |  | Commercial vertical accuracy requirements [3]m @[90]% are met - Yes/No.  If no, provide performance gaps @[90]% [m] | IIoT vertical accuracy requirements of [0.2]m @[90]% are met - Yes/No. If no, provide performance gaps @[90]% [m] | IIoT vertical accuracy requirements of [1]m at @[90]% are met - Yes/No.  If no, provide performance gaps @[90]% [m] |
| Case 3, InF FR1 DH ISD20, 100MHz, RANSAC, DL TDOA | Variable UE heights | 17.6 | 20.4 | 19.6 |
| Fixed UE heights | 15.4 | 18.24 | 17.4 |
| Case 4, InF FR1 SH ISD50, 100MHz, RANSAC, DL TDOA | Variable UE heights | Yes | 1.69 | 0.89 |
| Fixed UE heights | Yes | 0.7 | Yes |

*FR2 results*

**FR2 horizontal accuracy performance summary**

|  |  |  |  |
| --- | --- | --- | --- |
| 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]% |
| Case 5, Earliest beam pair | Yes. | Yes. | Yes. |
| Case 5, Strongest beam pair | Yes. | Yes. | Yes. |
| Case 6, Earliest beam pair | Yes. | Yes. | Yes. |
| Case 7, Earliest beam pair | Yes. | Yes. | Yes. |
| Case 7, Strongest beam pair | Yes. | 86% | 87% |
| Case 8, Earliest beam pair | Yes. | Yes. | Yes. |

**FR2 vertical accuracy performance summary**

|  |  |  |  |
| --- | --- | --- | --- |
| Simulation case  (Vertical Error) | 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]% |
| Case 6, Earliest beam pair | Yes. | Yes. | Yes. |
| Case 8, Earliest beam pair | Yes. | Yes. | Yes. |

*UMi/UMa/InH scenarios*

**FR2 horizontal accuracy performance summary**

|  |  |  |  |
| --- | --- | --- | --- |
| 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]% |
| Case 12 UMi Earliest | Yes. | Yes | Yes |
| Case 12 UMi Strongest | 70% | 55% | 58% |
| Case 13 InH Earliest | Yes. | Yes | Yes |
| Case 13 InH Strongest | Yes | Yes | Yes |

*Timing errors*

**FR2 horizontal accuracy performance summary**

|  |  |  |  |
| --- | --- | --- | --- |
| 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]% |
| Case 12 UMi Earliest | Yes. | Yes | Yes |
| Case 12 UMi Strongest | 70% | 55% | 58% |
| Case 13 InH Earliest | Yes. | Yes | Yes |
| Case 13 InH Strongest | Yes | Yes | Yes |

*PRS frequency domain stitching*

The impact of the impairments on the carrier aggregation was evaluated. The following set of configurations was considered:

* FR1 frequency band:
  + InH with phase offset between two Positioning Frequency Layers (PFLs)
  + InH with phase offset over 4 PFLs
  + InH with channel spacing between 2 PFLs
  + UMi with phase offset
  + UMi with time offset
  + InF with phase offset
* FR2 frequency band:
  + InF-SH with phase offset
  + InF-DH with phase offset
  + InH with phase offset
  + UMI with phase offset
  + UMI with time offset
  + InH with time offset

**FR2 horizontal accuracy performance summary - PRS frequency domain stitching**

|  |  |  |  |
| --- | --- | --- | --- |
| 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. |

*Kinematic constraint aware*

* Two scenarios are considered:
  + In scenario 1, the node computing the position knows the value of one of the coordinates, and only computes the other one. This is denoted in the figure legends as ‘D unknown in estimation and RMS calculation’ (where D=X or Y, depending on which coordinate is unknown).
  + In scenario 2, the node computing the position has no side information and computes both X and Y. However, the LCS client, i.e., the consumer of the computed (X,Y) position, knows the value of one of the coordinates, and thus ignores that one and uses only the other one.

**FR2 horizontal accuracy performance summary - kinematic constraint aware positioning**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Case ID | Kinematic constraint condition | 50% | 80% | 90% |
| Case 34  InF-SH, FR2,  DL-TDOA, RANSAC | XY is unknown in the estimation. XY is unknown in the RMS calculation | 0.024 | 0.033 | 0.049 |
| X is unknown in the estimation. X is unknown in the RMS calculation | 0.012 | 0.017 | 0.024 |
| XY is unknown in the estimation. X is unknown in the RMS calculation | 0.012 | 0.017 | 0.024 |
| Y is unknown in the estimation. Y is unknown in the RMS calculation | 0.017 | 0.024 | 0.031 |
| XY is unknown in the estimation. Y is unknown in the RMS calculation | 0.017 | 0.026 | 0.036 |
| Case 35 InF-DH, FR2,  DL-TDOA, RANSAC | XY is unknown in the estimation. XY is unknown in the RMS calculation | 0.030 | 0.038 | 0.058 |
| X is unknown in the estimation. X is unknown in the RMS calculation | 0.014 | 0.021 | 0.029 |
| XY is unknown in the estimation. X is unknown in the RMS calculation | 0.016 | 0.023 | 0.034 |
| Y is unknown in the estimation. Y is unknown in the RMS calculation | 0.018 | 0.028 | 0.038 |
| XY is unknown in the estimation. Y is unknown in the RMS calculation | 0.018 | 0.029 | 0.044 |
| Case 36 InH,  FR2  DL-TDOA, RANSAC | XY is unknown in the estimation. XY is unknown in the RMS calculation | 0.031 | 0.046 | 0.071 |
| X is unknown in the estimation. X is unknown in the RMS calculation | 0.012 | 0.019 | 0.026 |
| XY is unknown in the estimation. X is unknown in the RMS calculation | 0.013 | 0.019 | 0.028 |
| Y is unknown in the estimation. Y is unknown in the RMS calculation | 0.022 | 0.031 | 0.044 |
| XY is unknown in the estimation. Y is unknown in the RMS calculation | 0.023 | 0.035 | 0.053 |

*RTT + AOA fusion*

The RTT+AOA positioning method performance is evaluated in FR1 band for the UMi scenario.

Two cases are compared:

* RTT+AOA, Rel.16 baseline report with a single AOA
* RTT+AOA, with multiple AOA reporting

The following results for the positioning error are obtained:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  | 50% | 67% | 80% | 90% |
| Case 37, UMI, FR1,RTT+AoA, With Delta Tau, Perfect Sync, No Timing Errors, NR Rel-16 Baseline | (Optional) All UEs | 2.6 | 4.4 | 5.8 | 7.3 |
| Case 37, UMI, FR1,RTT, With Delta Tau, Perfect Sync, No Timing Errors, AoA & UL PDP Enhancement | (Optional) All UEs | 1.2 | 1.8 | 2.7 | 3.9 |

*Enhancement on additional path reporting*

The DL-TDOA and RTT positioning methods performance is evaluated in FR1 band for the UMi scenario.

Two cases are compared:

* DL-TDOA:
  + Rel.16 baseline report with RSTD and 2 additional paths
  + Enhancement, reporting of 8 time domain paths and their relative power

The following results for the positioning error are obtained:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  | 50% | 67% | 80% | 90% |
| Case 38, UMI, FR1,DL-TDOA, With , Perfect Sync, No Timing Errors, NR Rel-16 Baseline | (Optional) All UEs | 4.1 | 5.2 | 6.8 | 9 |
| Case 38, UMI, FR1,DL-TDOA, With , Perfect Sync, No Timing Errors, UL PDP Enhancement | (Optional) All UEs | 3.6 | 4.85 | 6 | 8 |

Two cases are compared:

* RTT:
  + Rel.16 baseline
  + UL-PDP report

The following results for the positioning error are obtained:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  | 50% | 67% | 80% | 90% |
| Case 39, UMI, FR1, RTT, With Delta Tau, Perfect Sync, No Timing Errors, NR Rel-16 Baseline | (Optional) All UEs | 3.38 | 4.9 | 6.2 | 9 |
| Case 39, UMI, FR1, RTT, With Delta Tau, Perfect Sync, No Timing Errors, UL PDP Enhancement | (Optional) All UEs | 1.6 | 2.4 | 3.4 | 4.7 |

*Genie LOS and outlier rejection comparison*

The ideal LOS link identification and the outlier rejection techniques are compared for the InF-DH scenario in FR1 frequency band.

The following results for the positioning error are obtained:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | 50% | 67% | 80% | 90% |
| Case 40, InF FR1 DH ISD20, 100MHz, LOS Genie + Link Quality | 0.36 | 4.08 | 10.28 | 35.65 |
| Case 40, InF FR1 DH ISD20, 100MHz, RANSAC | 0.085m | 0.52m | 2.17m | 8.25m |

**Physical layer latency**

The following estimation of the physical layer latency range for Rel.16 was provided:

* UE-Assisted DL-only Positioning, RRC Connected State: [57 - 823] ms
* UE-based DL-only Positioning, RRC Inactive State, External Client: [35.3 - 803.5] ms
* UE-based DL-only Positioning, RRC Connected State, UE Internal-client: [46 - 811] ms
* UE-based DL-only Positioning, RRC Inactive State, UE internal-client: [8 - 780] ms
* UE-Assisted MRTT Positioning, RRC Connected State: [59 - 823] ms

**Proposals for physical latency reduction**

Proposals (with potential latency reduction estimates for the best case):

* 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: potential gain 10 msec
* Support DCI/MAC-CE triggering of Measurement gaps (MG) for the purpose of positioning measurements: potential gain at least 30 msec
* Fast/real-time processing of short PRS instances: potential gain at least 1.5 ms
  + Support Enhanced PRS processing capabilities
  + Support partially-staggered or no-staggered DL-PRS transmissions
* Support Low-layer (e.g. UL MAC-CE or UCI) Measurement Reporting towards the serving gNB: potential gain 2 ms

## Source #16

In [[16], vivo], the evaluation of Rel.16 positioning methods and the Rel.17 potential enhancements are provided. The positioning accuracy, latency, network efficiency, and UE efficiency are analysed. The evaluations are performed in FR1 and FR2 frequency bands.

The following set of scenarios is considered:

* InF-SH/InF-DH baseline scenarios
* IOO scenario

The following positioning techniques are evaluated:

* FR1 band:
  + DL-TDOA, UL-AOA, UL-TDOA+UL-AOA, Multi-RTT, AOA+ZOA
* FR2 band:
  + DL-TDOA, UL-TDOA, Multi-RTT

**Accuracy – Rel.16 positioning solutions**

*Horizontal accuracy evaluation*

*Downlink only evaluation*

Observations:

* For Rel.16 DL-TDOA positioning, the performance target [0.2m 90%] can be achieved in InF-SH with perfect synchronization for convex UEs, and in InF-SH with perfect synchronization for all UEs for FR2, but cannot be achieved in other cases in InF-SH.
* For Rel.16 DL-TDOA positioning, the performance target [0.2m 90%] can be achieved in InF-DH with perfect synchronization for convex UEs for FR2, but cannot be achieved in other cases in InF-DH.
* The positioning performance of DL-TDOA degraded significantly with 50ns synchronization error.
* For DL-TDOA positioning with the DH clutter parameter {0.6,6,2}, the performance target [0.2m 90%] cannot be achieved and the performance gap is nearly 18 m.

*Uplink only evaluation*

Observations:

* For Rel.16 UL-TDOA positioning, the performance target [0.2m 90%] can be achieved in InF-SH with perfect synchronization for convex UEs, and in InF-SH with perfect synchronization for all UEs for FR2, but cannot be achieved in other cases in InF-SH.
* For Rel.16 UL-TDOA positioning, the performance target [0.2m 90%] can be achieved in InF-DH with perfect synchronization for convex UEs for FR2, but cannot be achieved in other cases in InF-DH.
* For Rel.16 UL-AOA positioning, the performance target [0.2m 90%] cannot be achieved in InF-SH and InF-DH.
* Compared to DL-TDOA or UL-TDOA, sync error has little effect on positioning performance on UL-AOA.
* For Rel.16 UL-TDOA+AOA positioning, the performance target [0.2m 90%] cannot be achieved in InF-SH and InF-DH.
* Compared to UL-AOA, UL-TDOA+AOA can improve the positioning accuracy to some extent.

*Downlink and uplink evaluation*

Observations:

* For Rel.16 Multi-RTT positioning, the performance target [0.2m 90%] can be achieved in InF-SH for convex UEs, and in InF-SH for all UEs for FR2, but cannot be achieved in InF-SH in other cases.
* For Rel.16 Multi-RTT positioning, the performance target [0.2m 90%] can be achieved in InF-DH for convex UEs for FR2, but cannot be achieved in other cases in InF-DH.
* Compared to DL-TDOA and UL-TDOA, Multi-RTT can mitigate the positioning error caused by synchronization error between network nodes.

*Vertical accuracy evaluation*

Observations:

* For vertical evaluation with DL-TDOA, the performance target [1m 90%] can be achieved in InF-SH and InF-DH scenarios for FR1 with baseline assumptions.
* For vertical evaluation with AOA+ZOA technique, the performance target [1m 90%] can be achieved in InF-SH scenario but not in InF-DH scenario for FR1 with baseline assumptions.

*Horizontal accuracy for IOO scenario*

Observations:

* For IOO scenario, the performance target [1m 90%] can be achieved with perfect synchronization.

**Accuracy – positioning enhancements**

*Outlier determination/rejection*

*Downlink only*

Observations:

* For DL-TDOA positioning, the performance target [0.2m 90%] can be achieved in InF-SH and InF-DH with perfect synchronization for convex UEs with enhancement.
* For DL-TDOA positioning, the performance target [0.2m 90%] can be achieved in InF-SH for FR2 with perfect synchronization for all UEs with enhancement, but cannot be achieved in other cases for all UEs.

*Uplink only*

Observations:

* For UL-TDOA positioning, the performance target [0.2m 90%] can be achieved in InF-SH and InF-DH with perfect synchronization for convex UEs with enhancement.
* For UL-TDOA positioning, the performance target [0.2m 90%] can be achieved in InF-SH for FR2 with perfect synchronization for all UEs with enhancement, but cannot be achieved in other cases for all UEs.

*Downlink and uplink*

Observations:

* For Multi-RTT positioning, the performance target [0.2m 90%] can be achieved in InF-SH and InF-DH for convex UEs with enhancement.
* For Multi-RTT positioning, the performance target [0.2m 90%] can be achieved in InF-SH and InF-DH for FR2 for all UEs with enhancement, but cannot be achieved in other cases for all UEs.

*Outlier determination/rejection and LOS detection*

Observations:

* Outlier determination/rejection techniques have better positioning accuracy performance than LOS detection.
* The positioning performance of LOS/NLOS detection method degrades as LOS detection error probability increases.

Proposals:

* LOS/NLOS detection/identification should not be considered in Rel-17.

*Timing measurement reporting granularity*

Observations:

* The minimum Rel.16 granularity of timing measurement reports is enough to avoid degradation in IIoT scenarios and meet positioning requirements.

*Tx/Rx timing error*

Observations:

* With the TX/RX timing error 0.5ns, the performance target [0.2m 90%] cannot be achieved in both InF-SH and InF-DH.
* For DL-TDOA, the UE timing error has little impact on positioning accuracy, while the BS timing error causes some degradation on positioning performance.
* For Multi-RTT, the UE timing error and BS timing error both cause degradation in accuracy.

*Aggregation of DL positioning frequency layers*

Observations:

* For ideal aggregation of multiple DL positioning frequency 50M+50M, performance target [0.2m 90%] cannot be achieved in both InF-SH and InF-DH.
* For ideal aggregation of multiple DL positioning frequency 50M+50M, the performance is worse than 100M but better than 50M.

Proposals:

* The performance impact of non-ideal aggregation of multiple DL positioning frequency should be further studied.

**Physical layer latency – Rel.16 positioning solutions**

Summary for physical layer latency:

* [Case 1], [IIoT/ Commercial], [Frequency Band], [DL-TDOA/AoD],[UE-A]: 64ms~
* [Case 2], [IIoT/ Commercial], [Frequency Band], [DL-TDOA/AoD],[UE-B] Source [Network]/Destination [Network]: 66 ms ~
* [Case 3], [IIoT/ Commercial], [Frequency Band], [DL-TDOA/AoD],[UE-B] Source [UE]/Destination [UE]: 55.5ms~
* [Case 4], [IIoT/ Commercial], [Frequency Band], [UL-TDOA/UL-AoA], [periodic SRS]: 30.5ms~
* [Case 5], [IIoT/ Commercial], [Frequency Band], [UL-TDOA/UL-AoA], [A- SRS]: 11ms~
* [Case 6], [IIoT/ Commercial], [Frequency Band], [Multi-RTT]: 94.5+TAlign\_DL\_UL~

Observations:

* The longer period of positioning reference signal and measurement gap, the greater the latency.
* 10ms physical layer latency cannot be reached with Rel-16 solutions.

Proposals:

* Physical layer latency needs to be reduced in Rel-17.

**Physical layer latency – Rel.17 enhancements**

Summary for physical layer latency (gain of enhancements):

* [Case 7], [on-demand/aperiodic PRS]: Rel.16 latency / gain over Rel.16 44.5ms~ / 19.5ms~
* [Case 8], [on-demand/aperiodic MG]: Rel.16 latency / gain over Rel.16 27.5ms~ / 36.5ms~
* [Case 9], [Positioning BWP]: Rel.16 latency / gain over Rel.16 28.5ms~ / 35.5ms~
* [Case 10], [physical layer triggered]: Rel.16 latency / gain over Rel.16 44ms~ / 20ms~
* [Case 11], [combination scheme]: Rel.16 latency / gain over Rel.16 5ms~ / 59ms~

Observations:

* 10ms physical layer latency can be reached with the combination of on-demand/aperiodic PRS, on-demand/aperiodic MG, Positioning BWP, and physical layer triggered request/report.

Proposals:

* On-demand/aperiodic PRS, on-demand/aperiodic MG, Positioning BWP, and physical layer triggered need to be studied in Rel-17 for reducing latency.

*The latency of Idle/ inactive to the connected mode*

Observations:

* Additional latency of 40~200ms will be introduced if the UE switches to connected state from idle state for positioning measurement and report.

**Network and UE efficiency – Rel.16 solutions**

Observations:

* The network efficiency exceeds 100% in some FR2 cases.
* The MGL/MGRP (UE efficiency) exceeds 30% in some FR2 cases.

Proposals:

* The network efficiency and UE efficiency for low latency positioning needs to be enhanced.

**Network and UE efficiency – Rel.17 enhancements**

Observations:

* The network and device efficiency will be reduced by on-demand PRS within the same level latency compared to periodic PRS.
* The network and device efficiency of aperiodic PRS is multiple of the number of activations.
* By extending the PRS period to 2 times(160ms to 320ms), 22.03% power saving gain is shown ,comparing with the baseline assumption
* By extending the PRS period to 4 times(160ms to 640ms), 33.05 % power saving gain is shown, comparing with the baseline assumption
* When configuring concentrated PRS measurement(1 concentrated PRS occasion every 160ms), 18.77% power saving gain is shown, comparing with the distributed PRS measurement (4 distributed PRS occasion every 160ms)
* By adding the PRS MTC window to limit PRS measurement in 2ms (from 4ms to 2ms), 20.48% power saving gain is shown ,comparing with PRS measurement without PRS-MTC .
* By reducing the number of TRPs for PRS measurement (from 8 TRPs to 4 TRPs), 8.51% power saving gain is shown ,comparing with the baseline assumption.
* By reducing the number of frequency layer to 2 (from 4 to 2), 36.91% power saving gain is shown; by reducing number of frequency layer to 1 (from 4 to 1), 57.26% power saving gain is shown.
* For PRS measurements, the following approaches are benefit for power saving.
  + Extending PRS period
  + Defining positioning measurement window
  + Concentrated PRS distribution
  + Reducing the number of TRPs to be measured
  + Reducing the number of positioning frequency layers to be measured
* Under the premise of idle state measurement, positioning report in the idle state can obtain 44.32% power saving gain compared to report in connected state.
* Compared to positioning measurement and report all in the connected state, positioning measurement and report in the idle state can obtain at least 48.38% power saving gain.

## Source #17

In [[17], Intel Corporation], the evaluation of Rel.16 positioning methods and the Rel.17 potential enhancements are provided. The positioning accuracy and latency are analysed. The evaluations are performed in FR1 and FR2 frequency bands.

The following set of scenarios is considered:

* InF-SH/InF-DH baseline scenarios, with and without gNB/UE TX/RX timing errors

The following positioning techniques are evaluated:

* FR1 band:
  + DL-TDOA, UL-TDOA, Multi-RTT, Multi-RTT+AOA
* FR2 band:
  + DL-TDOA, UL-TDOA, Multi-RTT, Multi-RTT+AOA

**Accuracy – Rel.16 baseline performance**

Observations:

* Performance of the Rel.16 positioning techniques highly depends on the measurement data set used in the estimation
* Usage of the LOS links only provides better performance compared to the case when both LOS and NLOS links are utilized
* The target performance can be achieved in InF-SH scenario, with high probability of LOS links
* The target performance cannot be achieved in InF-DH scenario, with high probability of NLOS links

**Accuracy – Rel.17 enhancements**

*LOS/NLOS Classification*

Observations:

* The algorithm for LOS/NLOS classification provides better performance results compared to the conventional outlier rejection RAIM algorithm known in the literature

*Performance of Multi-RTT + AoA (Hybrid Positioning)*

Observations:

* Combination of the Multi-RTT and vertical AoA measurements further improves positioning performance in the InF scenarios

*Aggregation of NR Positioning Frequency Layers*

Observations:

* Usage of the larger aggregated bandwidth allows to improve performance significantly and achieve target performance requirements

*Compensation of gNB/UE Synchronization and Calibration Errors*

Observations:

* The TX/RX timing errors can significantly deteriorate the positioning performance
* Usage of compensation method for TX/RX timing errors substantially improves the performance
* There is still a margin for improvement between the practical and ideal performance and other timing errors compensation techniques can be potentially considered.

**Latency analysis – Rel.16 baseline solutions**

*Latency analysis for Rel.16 DL-TDOA / DL-AOD*

* Summary of latency components:
  + Sum of L1 components (except DL PRS alignment time and DL PRS report delay): 4,5714 ms
  + Sum of L2+L3 components: [36 ms TBD by RAN WG2]
  + DL PRS alignment time: 20 ms
  + DL PRS report delay: 68.5 ms
* If only L1 latency components are considered (except DL PRS alignment time and DL PRS report delay), it is feasible to meet 10ms target requirements for DL-TDOA/DL-AOD
* DL-TDOA / DL-AoD physical layer latency is dominated by the following latency components
  + Higher layer (LPP/RRC) processing/configuration time
  + Multiple DL/UL transactions before actual DL PRS processing, including
    - Location request, measurement gap request/configuration and measurement report
  + DL PRS alignment time
    - Rel.16 Measurement Gap (MG) design has certain limitations in terms of MG periodicity, length, RRC configuration time. Therefore, it is difficult to reduce latency even if DL PRS are allocated at minimum period = 4ms.
    - Periodic DL PRS allocation with low periodicity (min of 4ms). Although it is beneficial for positioning latency, such DL PRS resource utilization is very high
  + DL PRS report delay
    - According to the latest draft of core requirements in TS 38.133 for NR positioning RSTD measurements, UE is expected to measure DL PRS-RSTD on four consecutive DL PRS resource periods, that imposes significant delay and thus need to be reconsidered in Rel.17.

*Latency analysis for Rel.16 UL-TDOA / UL-AOA*

* Summary of latency components:
  + Sum of L1 components: 2,7678 ms
  + Sum of L2/L3 components: 16 ms
* Physical layer latency for UL-TDOA and UL-AoA is dominated by SRS for positioning configuration component (RRC configuration delay) that utilizes 10 out of 16 ms total latency for considered reference system configuration.

*Latency analysis for Rel.16 Multi-RTT*

* Summary of latency components:
  + Sum of L1 components (except DL PRS alignment time and DL PRS report delay: 7,3393 ms
  + Sum of L2/L3 components: 45 ms (TBD by RAN WG2)
  + DL PRS alignment time: 20 ms
  + DL PRS report delay: 68.5 ms
* Physical layer latency for Multi-RTT is dominated by
  + Higher layer (LPP/RRC) processing/configuration time
  + DL PRS alignment time
  + DL PRS report delay

**Latency analysis – Rel.17 enhancements**

*Latency analysis for NR positioning protocol*

Observations

* DL-TDOA latency of L1 components = 3.8839 ms
  + Estimated higher layer signaling time is up to 4ms
* UL-TDOA latency of L1 components = 1.9018 ms
  + Estimated higher layer signaling time is up to 3ms
* Multi-RTT latency of L1 components = 4.1875 ms
  + Estimated higher layer signaling time is up to 4ms

*Latency reduction for UEs in RRC\_IDLE / RRC\_INACTIVE states*

In terms of NR positioning enhancements, the support of the following functionality should be considered:

* Support of NR positioning techniques for UEs in RRC\_INACTIVE state w/ and w/o transition to RRC\_CONNECTED state including the following enhancements
  + Transmission of SRS for positioning following PRACH and MSG-A transmission
  + Transmission of SRS for positioning triggered by signaling from gNB
  + Request of DL PRS allocation by UE and DL PRS activation by gNB
  + UE DL PRS measurement and report

The latency analysis of transition time from INACTIVE to CONNECTED state (depends on configurations/deployment):

* The maximum latency = 18.5 ms;
* The minimum latency = 11.3 ms;

# Summary of Discussion Aspects

## Positioning Accuracy Evaluation

### Summary of Accuracy Analysis for Rel.16 Solutions

#### InF-SH/InF-DH Scenarios – perfect sync and zero TX/RX timing errors

The results for the horizontal positioning accuracy evaluation in the InF-SH and InF-DH scenarios were presented by 12 out of 17 sources. The results for the vertical positioning accuracy evaluation were presented by 5 out of 17 sources.

All results are presented for the perfect synchronization and zero gNB/UE TX/RX timing errors.

Two types of requirements for the horizontal positioning accuracy were considered, including [0.2m@90%](mailto:0.2m@90%25) and [0.5m@90%](mailto:0.5m@90%25). Two types of requirements for the vertical positioning accuracy were considered, including [0.2m@90%](mailto:0.2m@90%25) and [1.0m@90%](mailto:1.0m@90%25).

Summary for the horizontal positioning accuracy (12 sources in total):

* InF-SH:
  + FR1 band:
    - Requirement [[0.2m@90%](mailto:0.2m@90%25)]: YES: 3, NO: 9
    - Requirement [[0.5m@90%](mailto:0.5m@90%25)]: YES: 7, NO: 5
  + FR2 band:
    - Requirement [[0.2m@90%](mailto:0.2m@90%25)]: YES: 4, NO: 3
    - Requirement [[0.5m@90%](mailto:0.5m@90%25)]: YES: 8, NO: 1
* InF-DH:
  + FR1 band:
    - Requirement [[0.2m@90%](mailto:0.2m@90%25)]: YES: 1, NO: 11
    - Requirement [[0.5m@90%](mailto:0.5m@90%25)]: YES: 2, NO: 10
  + FR2 band:
    - Requirement [[0.2m@90%](mailto:0.2m@90%25)]: YES: 3, NO: 6
    - Requirement [[0.5m@90%](mailto:0.5m@90%25)]: YES: 3, NO: 6

Summary for the vertical positioning accuracy (5 sources in total):

* InF-SH:
  + FR1 band:
    - Requirement [[0.2m@90%](mailto:0.2m@90%25)]: YES: 0, NO: 4
    - Requirement [[1.0m@90%](mailto:1.0m@90%25)]: YES: 2, NO: 2
  + FR2 band:
    - Requirement [[0.2m@90%](mailto:0.2m@90%25)]: YES: 1, NO: 3
    - Requirement [[1.0m@90%](mailto:1.0m@90%25)]: YES: 3, NO: 1
* InF-DH:
  + FR1 band:
    - Requirement [[0.2m@90%](mailto:0.2m@90%25)]: YES: 0, NO: 4
    - Requirement [[1.0m@90%](mailto:1.0m@90%25)]: YES: 2, NO: 2
  + FR2 band:
    - Requirement [[0.2m@90%](mailto:0.2m@90%25)]: YES: 0, NO: 3
    - Requirement [[1.0m@90%](mailto:1.0m@90%25)]: YES: 0, NO: 3

**Conclusions:**

* It is problematic to meet the horizontal positioning accuracy requirement of [[0.2m@90%](mailto:0.2m@90%25)] in InF-DH scenario, especially for FR1 band.
* There is no sufficient number of presented results for the vertical positioning evaluation to make a clear conclusion.

The detail summary of the results can be found in Table 1.

Table 1: Positioning accuracy summary for InF-SH and InF-DH scenarios.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Source** | **Horizontal accuracy** | | **Vertical accuracy** | |
| **0.2m@90%** | **0.5m@90%** | **0.2m@90%** | **1.0m@90%** |
| Source #1  [[1], Huawei, HiSi] | InF-SH, FR1:  NO | InF-SH, FR1:  YES | InF-SH, FR1:  - | InF-SH, FR1:  - |
| InF-SH, FR2:  YES | InF-SH, FR2:  YES | InF-SH, FR2:  - | InF-SH, FR2:  - |
| InF-DH, FR1:  NO | InF-DH, FR1:  NO | InF-DH, FR1:  - | InF-DH, FR1:  - |
| InF-DH, FR2:  NO | InF-DH, FR2:  NO | InF-DH, FR2:  - | InF-DH, FR2:  - |
| Source #2  [[2], BUPT] | InF-SH, FR1:  NO | InF-SH, FR1:  NO | InF-SH, FR1:  - | InF-SH, FR1:  - |
| InF-SH, FR2:  NO | InF-SH, FR2:  YES | InF-SH, FR2:  - | InF-SH, FR2:  - |
| InF-DH, FR1:  NO | InF-DH, FR1:  YES | InF-DH, FR1:  - | InF-DH, FR1:  - |
| InF-DH, FR2:  YES | InF-DH, FR2:  YES | InF-DH, FR2:  - | InF-DH, FR2:  - |
| Source #3  [[3], ZTE] | InF-SH, FR1:  NO | InF-SH, FR1:  NO | InF-SH, FR1:  NO | InF-SH, FR1:  YES |
| InF-SH, FR2:  YES | InF-SH, FR2:  YES | InF-SH, FR2:  NO | InF-SH, FR2:  YES |
| InF-DH, FR1:  NO | InF-DH, FR1:  NO | InF-DH, FR1:  NO | InF-DH, FR1:  NO |
| InF-DH, FR2:  NO | InF-DH, FR2:  NO | InF-DH, FR2:  NO | InF-DH, FR2:  NO |
| Source #4  [[4], CATT] | InF-SH, FR1:  NO | InF-SH, FR1:  YES | InF-SH, FR1:  NO | InF-SH, FR1:  NO |
| InF-SH, FR2:  YES | InF-SH, FR2:  YES | InF-SH, FR2:  NO | InF-SH, FR2:  YES |
| InF-DH, FR1:  YES | InF-DH, FR1:  YES | InF-DH, FR1:  NO | InF-DH, FR1:  YES |
| InF-DH, FR2:  NO | InF-DH, FR2:  NO | InF-DH, FR2:  NO | InF-DH, FR2:  NO |
| Source #7  [[7], OPPO] | InF-SH, FR1:  NO | InF-SH, FR1:  YES | InF-SH, FR1:  - | InF-SH, FR1:  - |
| InF-SH, FR2:  - | InF-SH, FR2:  - | InF-SH, FR2:  - | InF-SH, FR2:  - |
| InF-DH, FR1:  NO | InF-DH, FR1:  NO | InF-DH, FR1:  - | InF-DH, FR1:  - |
| InF-DH, FR2:  - | InF-DH, FR2:  - | InF-DH, FR2:  - | InF-DH, FR2:  - |
| Source #8  [[8], Nokia, Nokia Shanghai Bell] | InF-SH, FR1:  NO | InF-SH, FR1:  NO | InF-SH, FR1:  - | InF-SH, FR1:  - |
| InF-SH, FR2:  - | InF-SH, FR2:  - | InF-SH, FR2:  - | InF-SH, FR2:  - |
| InF-DH, FR1:  NO | InF-DH, FR1:  NO | InF-DH, FR1:  - | InF-DH, FR1:  - |
| InF-DH, FR2:  - | InF-DH, FR2:  - | InF-DH, FR2:  - | InF-DH, FR2:  - |
| Source #9  [[9], Sony] | InF-SH, FR1:  NO | InF-SH, FR1:  NO | InF-SH, FR1:  - | InF-SH, FR1:  - |
| InF-SH, FR2:  NO | InF-SH, FR2:  YES | InF-SH, FR2:  - | InF-SH, FR2:  - |
| InF-DH, FR1:  NO | InF-DH, FR1:  NO | InF-DH, FR1:  - | InF-DH, FR1:  - |
| InF-DH, FR2:  NO | InF-DH, FR2:  NO | InF-DH, FR2:  - | InF-DH, FR2:  - |
| Source #13  [[13], CEWiT, IITM, Tejas Networks, IITH, Reliance Jio, Saankhya Labs], | InF-SH, FR1:  NO | InF-SH, FR1:  NO | InF-SH, FR1:  - | InF-SH, FR1:  - |
| InF-SH, FR2:  - | InF-SH, FR2:  - | InF-SH, FR2:  - | InF-SH, FR2:  - |
| InF-DH, FR1:  NO | InF-DH, FR1:  NO | InF-DH, FR1:  - | InF-DH, FR1:  - |
| InF-DH, FR2:  - | InF-DH, FR2:  - | InF-DH, FR2:  - | InF-DH, FR2:  - |
| Source #14  [[14], Ericsson] | InF-SH, FR1:  YES | InF-SH, FR1:  YES | InF-SH, FR1:  - | InF-SH, FR1:  - |
| InF-SH, FR2:  YES | InF-SH, FR2:  YES | InF-SH, FR2:  - | InF-SH, FR2:  - |
| InF-DH, FR1:  NO | InF-DH, FR1:  NO | InF-DH, FR1:  - | InF-DH, FR1:  - |
| InF-DH, FR2:  NO | InF-DH, FR2:  NO | InF-DH, FR2:  - | InF-DH, FR2:  - |
| Source #15  [[15], Qualcomm Incorporated] | InF-SH, FR1:  YES | InF-SH, FR1:  YES | InF-SH, FR1:  - | InF-SH, FR1:  - |
| InF-SH, FR2:  YES | InF-SH, FR2:  YES | InF-SH, FR2:  YES | InF-SH, FR2:  YES |
| InF-DH, FR1:  NO | InF-DH, FR1:  NO | InF-DH, FR1:  - | InF-DH, FR1:  - |
| InF-DH, FR2:  YES | InF-DH, FR2:  YES | InF-DH, FR2:  - | InF-DH, FR2:  - |
| Source #16  [[16], vivo] | InF-SH, FR1:  YES | InF-SH, FR1:  YES | InF-SH, FR1:  NO | InF-SH, FR1:  YES |
| InF-SH, FR2:  YES | InF-SH, FR2:  YES | InF-SH, FR2:  - | InF-SH, FR2:  - |
| InF-DH, FR1:  NO | InF-DH, FR1:  NO | InF-DH, FR1:  NO | InF-DH, FR1:  YES |
| InF-DH, FR2:  YES | InF-DH, FR2:  YES | InF-DH, FR2:  - | InF-DH, FR2:  - |
| Source #17  [[17], Intel Corporation] | InF-SH, FR1:  NO | InF-SH, FR1:  YES | InF-SH, FR1:  NO | InF-SH, FR1:  NO |
| InF-SH, FR2:  NO | InF-SH, FR2:  NO | InF-SH, FR2:  NO | InF-SH, FR2:  NO |
| InF-DH, FR1:  NO | InF-DH, FR1:  NO | InF-DH, FR1:  NO | InF-DH, FR1:  NO |
| InF-DH, FR2:  NO | InF-DH, FR2:  NO | InF-DH, FR2:  NO | InF-DH, FR2:  NO |

#### UMa/UMi/IOO Scenarios – perfect sync and zero TX/RX timing errors

The results for the horizontal positioning accuracy evaluation in the IOO scenario were presented by 3 out of 17 sources. The results for the positioning accuracy evaluation in the UMi scenario were presented by 3 out of 17 sources. The results for the positioning accuracy evaluation in the UMa scenario were presented by 2 of 17 sources.

All results are presented for the perfect synchronization and zero gNB/UE TX/RX timing errors.

The summary of the positioning accuracy results for the IOO scenario can be found in Table 2.

Table 2: Positioning accuracy summary for IOO scenario.

|  |  |  |
| --- | --- | --- |
| **Source** | **Horizontal accuracy** | **Vertical accuracy** |
| **1.0m@80%** | **3.0m@80%** |
| Source #8  [[8], Nokia, Nokia Shanghai Bell] | FR1: NO | - |
| Source #14  [[14], Ericsson] | FR1: YES  FR2: YES | - |
| Source #16  [[16], vivo] | FR1: YES  FR2: YES | - |

**Conclusions:**

* The horizontal positioning accuracy for the IOO scenario potentially can be met with the Rel.16 positioning methods.

The summary of the positioning accuracy results for the UMa scenario can be found in Table 3.

Table 3: Positioning accuracy summary for UMa scenario.

|  |  |
| --- | --- |
| **Source** | **Horizontal accuracy** |
| **10.0m@80%** |
| Source #14  [[14], Ericsson] | FR1: YES |
| Source #15  [[15], Qualcomm Incorporated] | FR1: YES |

**Conclusions:**

* The horizontal positioning accuracy for the UMa scenario can be met with the Rel.16 positioning methods.
* In source [[14], Ericsson], it is suggested to exclude UMa scenario from Rel.17 evaluations.

The summary of the positioning accuracy results for the UMi scenario can be found in Table 4.

Table 4: Positioning accuracy summary for UMi scenario.

|  |  |
| --- | --- |
| **Source** | **Horizontal accuracy** |
| **1.0m@80%** |
| Source #8  [[8], Nokia, Nokia Shanghai Bell] | FR1: NO |
| Source #14  [[14], Ericsson] | FR1: YES |
| Source #15  [[15], Qualcomm Incorporated] | FR1: YES |

**Conclusions:**

* The horizontal positioning accuracy for the UMi scenario can be potentially met with the Rel.16 positioning methods.

#### Synchronization errors and non-zero TX/RX timing errors

The results for the positioning evaluation with synchronization errors and/or gNB/UE TX/RX timing errors were presented by 6 out of 17 sources. It was shown that the synchronization and timing errors may cause a significant degradation of positioning accuracy.

The results from the different sources cannot be accurately compared due to different choice of the parameters in the errors distribution.

**Conclusions:**

* The synchronization errors and gNB/UE TX/RX timing errors may have a significant impact on the positioning accuracy.
* The X and Y parameters need to be defined in the gNB/UE TX/RX timing error model to facilitate accurate comparison of the presented results over different sources.

#### Observations / Conclusions on Performance of Rel.16 Solutions

1. **(On horizontal positioning accuracy in InF-SH)**
   * **Evaluation results for indoor factory scenario InF-SH (sparse high) show that this scenario is dominated by LOS links, which presence is beneficial for accurate UE positioning.**
   * **Sub-meter level of horizontal positioning accuracy is achieved by Rel.16 solutions (DL-TDOA, UL-TDOA, Multi-RTT and combination of hybrid solutions such as DL-TDOA+DL-AoD, UL-TDOA+UL AoA).**
   * **For the case without modeling synchronization and calibration errors**
     + **Results were provided by [12] out of [17] sources for FR1 and by [7-9] sources out of 17 for FR2**
       - **For evaluation in FR1 band, the following is observed with respect to target 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 evaluation in FR2 band, the following is observed with respect to target horizontal positioning accuracy:**
         1. **Accuracy of ≤** [**0.2m @ 90%**](mailto:0.2m@90%25) **is achieved in contributions from [4] sources and is not achieved in contributions from [3] sources**
         2. **Accuracy of ≤** [**0.5m @ 90%**](mailto:0.2m@90%25) **is achieved in contributions from [8] sources and is not achieved in contributions from [1] sources**
2. **(On horizontal positioning accuracy in InF-DH)**
   * **Evaluation results for indoor factory scenario InF-DH (dense high) show that this scenario is characterized by high probability of NLOS links, that have detrimental effect on accuracy of UE positioning due to NLOS excess time offset in propagation delay.**
   * **Target level of horizontal positioning accuracy is not achieved by Rel.16 solutions (DL-TDOA, UL-TDOA, Multi-RTT and combination of hybrid solutions such as DL-TDOA+DL-AoD, UL-TDOA+UL AoA) if no enhancements are considered**
   * **For the case without modeling synchronization and calibration errors**
     + **Results were provided by [12] out of [17] sources for FR1 and by [9] sources out of [17] for FR2**
       - **For evaluation in FR1 band, the following is observed with respect to target horizontal positioning accuracy:**
         1. **Accuracy of ≤** [**0.2m @ 90%**](mailto:0.2m@90%25) **is achieved in contributions from [1] sources and is not achieved in contributions from [11] sources**
         2. **Accuracy of ≤** [**0.5m @ 90%**](mailto:0.2m@90%25) **is achieved in contributions from [2] sources and is not achieved in contributions from [10] sources**
       - **For evaluation in FR2 band, the following is observed with respect to target 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 [6] sources**
         2. **Accuracy of ≤** [**0.5m @ 90%**](mailto:0.2m@90%25) **is achieved in contributions from [3] sources and is not achieved in contributions from [6] sources**
3. **(On positioning accuracy in UMa/UMi/IOO)**
   * **Evaluation results for optional IOO/UMi/UMa scenarios are provided by 3 out of 17 sources**
   * **The following is observed for horizontal positioning accuracy** 
     + **1m @ 80% is achieved for IOO/UMi by 2 out of 3 sources**
     + **10m @ 80% is achieved for UMa by 2 out of 3 sources**
   * **Considering small number of available sources, it is recommended to draw SI conclusions and observations based on evaluations for agreed InF scenarios only**
4. **(On impact of synchronization and gNB/UE TX/RX timing errors)**
   * **Evaluation results (provided by [6] out of [17] sources) have shown that synchronization errors and gNB/UE TX/RX timing have a significant impact on the UE positioning accuracy and deteriorate performance of the Rel.16 NR Positioning timing-based solutions**
   * **In terms of gNB/UE TX/RX timing errors, the values of X and Y parameters need to be defined in the gNB/UE TX/RX timing error model to facilitate use of common assumptions across different sources**
     + **[It is observed that companies use different values for parameters X and Y].**
   * **If synchronization and gNB/UE TX/RX timing errors are modelled without compensation techniques, the targeted IIoT accuracy requirements with sub-meter level positioning accuracy are not reached by timing-based solutions of the Rel.16 NR Positioning.**
   * **Accurate synchronization and small gNB/UE TX/RX timing errors are essential to achieve precise performance of the NR Positioning timing-based solutions.**
   * **The values of X and Y beyond [TBD] allow to achieve considered target positioning accuracies but the feasibility of X and Y needs to be confirmed by RAN4 WG**

### Summary of Accuracy Analysis for NR Positioning Enhancements

#### LOS / NLOS Identification and NLOS Mitigation

The results for the positioning accuracy enhancement using LOS/NLOS identification and NLOS mitigation methods were presented by 9 out of 17 sources.

In source [[1], Huawei, HiSi], the following observations were made for In-DH scenario:

* The LOS/NLOS detection achieves close performance to the Ideal LOS/NLOS detection
* Both the LOS/NLOS detection and the Ideal LOS/NLOS detection achieve the accuracy of less than 0.5m@90%
* The LOS/NLOS detection method achieves higher accuracy than the traditional RAIM method by tagging the channel as LOS or NLOS

In source [[3], ZTE], the following observations were made for In-DH scenario:

* When positioning is done without assistance information, the positioning performance degrades rapidly for UEs connected with small LOS communication links.
* If ideal classification of LOS and NLOS links is assumed, all cases meet sub-meter level positioning accuracy requirement.
* By utilizing Rician K-factor and coherence bandwidth as assistance information, positioning accuracy is significantly improved compared to without such assistance information, and sub-meter level positioning accuracy requirement can be fulfilled at the percentile of 90% UEs in FR2.

In source [[5], FUTUREWEI], the following observations were made for InF-SH/In-DH scenario:

* LOS (or NLOS) detection provides a robust method to improve the positioning accuracy. The gains that can be obtained vary dependent on channel condition specifically the number of LOS (or NLOS) links in the channel.
* LOS (or NLOS) identification based on detection of the transmitted PRSs polarization is shown to be feasible and can identify and reduce the probability of selecting a NLOS link as one of the selected paths for the positioning estimation calculation.

In source [[7], OPPO], the following observations were made for InF-SH scenario:

* Implementing NLOS mitigation can improve positioning accuracy
* Implementing LOS classification method can improve the positioning accuracy, but the errors in LOS classification may decrease performance
* In InF-SH scenario, gain from the method of LOS classification is marginal

In source [[9], Sony], the following observations were made for InF-DH scenario:

* The enhancement of NLOS detection algorithm from Rel.16 to Rel.17 improves the horizontal positioning accuracy, especially in InF-DH scenario. The improvement can be up to 1.7 m in InF-DH FR1 case.

In source [[13], CEWiT, IITM, Tejas Networks, IITH, Reliance Jio, Saankhya Labs], the following observations were made for InF-DH scenario:

* NLOS path will degrade the positioning accuracy by 5 to 10 times. So, LOS/NLOS indication is necessary for achieving sub -meter level accuracy.
* LOS/NLOS path indication along with power and angle reporting of corresponding path should be specified in Rel 17.

In source [[15], Qualcomm Incorporated], the ideal LOS link identification and the outlier rejection techniques are compared for the InF-DH scenario in FR1 frequency band.

The following results for the positioning error are obtained:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | 50% | 67% | 80% | 90% |
| Case 40, InF FR1 DH ISD20, 100MHz, LOS Genie + Link Quality | 0.36 | 4.08 | 10.28 | 35.65 |
| Case 40, InF FR1 DH ISD20, 100MHz, RANSAC | 0.085m | 0.52m | 2.17m | 8.25m |

In source [[16], vivo], the following observations were made for InF-DH scenario:

* Outlier determination/rejection techniques have better positioning accuracy performance than LOS detection.
* The positioning performance of LOS/NLOS detection method degrades as LOS detection error probability increases.
* LOS/NLOS detection/identification should not be considered in Rel-17.

In source [[17], Intel Corporation], the following observations were made for InF-DH scenario:

* The algorithm for LOS/NLOS classification provides better performance results compared to the conventional outlier rejection RAIM algorithm known in the literature

1. **(On LOS/NLOS identification and NLOS mitigation)**
   * **Evaluation results for LOS/NLOS identification and NLOS mitigation in indoor factory scenario were provided by [9] sources out of [17]:**
     + **The [6] sources show that LOS/NLOS identification provides significant performance enhancements and reporting of the LOS/NLOS link type need to be considered as NR positioning enhancement. LOS/NLOS detection algorithm has better performance compared to the conventional outlier rejection algorithms (RAIM/RANSAC).**
     + **The [1] source shows that implementing NLOS mitigation can improve positioning accuracy. In InF-SH scenario, gain from the method of LOS classification is marginal.**
     + **The [2] sources show that the outlier rejection algorithm (RAIM) has better performance than LOS/NLOS detection algorithm.**
   * **LOS/NLOS identification and NLOS mitigation are recommended as a solution to overcome the problem of NLOS excess propagation delay offset for indoor factory scenarios especially in the InF-DH scenario.**

#### Aggregation of Positioning Frequency Layers

The results for the positioning accuracy enhancement using aggregation of NR positioning frequency were presented by 4 out of 17 sources. The impact of phase discontinuity and other impairments was investigated.

In source [[1], Huawei, HiSi], the following observations were made for aggregation of positioning frequency layers:

* PRS/SRS frequency 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.

In source [[15], Qualcomm Incorporated], the following impairments for aggregation of positioning frequency layers were modelled:

* InH with phase offset between two Positioning Frequency Layers (PFLs)
* InH with phase offset over 4 PFLs
* InH with channel spacing between 2 PFLs
* UMi with phase offset
* UMi with time offset
* InF with phase offset

In source [[16], vivo], the following observations were made for aggregation of DL positioning frequency layers:

* For ideal aggregation of multiple DL positioning frequency 50M+50M, performance target [0.2m 90%] cannot be achieved in both InF-SH and InF-DH.
* For ideal aggregation of multiple DL positioning frequency 50M+50M, the performance is worse than 100M but better than 50M.

In source [[17], Intel Corporation],

* Usage of the larger aggregated bandwidth allows to improve performance significantly and achieve target performance requirements.

1. **(On aggregation of NR positioning frequency layers)**
   * **Evaluation results for aggregation of positioning frequency layers were provided by [4] sources out of [17]**
   * **Aggregation of NR positioning frequency layers improves positioning accuracy significantly and can help to achieve the target IIoT positioning accuracy.**
   * **Further work is needed to decide on details of supported configurations for NR positioning frequency layer aggregation including practical impairments such as: channel spacing, timing offset over frequency layers, frequency offset over frequency layers, phase discontinuity and possible amplitude imbalance.**

#### On Network Synchronization / gNB/UE TX/RX Timing Errors

The results for the positioning accuracy enhancement using synchronization and gNB/UE TX/RX timing errors reporting were presented by 2 out of 17 sources.

In source [[13], CEWiT, IITM, Tejas Networks, IITH, Reliance Jio, Saankhya Labs], the following observations were made:

* Network synchronization error is critical factor in Rel 17 positioning enhancement as it degrades the positioning accuracy significantly. Synchronization correction techniques are necessary to be specified in Rel 17.
* PRS based network synchronization error correction techniques should be specified in Rel 17 to achieve required accuracy.

In source [[17], Intel Corporation], the following observations were made:

* The TX/RX timing errors can significantly deteriorate the positioning performance
* Usage of compensation method for TX/RX timing errors substantially improves the performance

1. **(On Network Synchronization / gNB / UE TX/RX Timing Errors)**
   * **Accurate network synchronization as well as solutions to cope with gNB/UE TX/RX timing errors are needed to achieve precise positioning**
     + **FFS impact on specification**

#### Other Evaluated Enhancements

In this section we provide list of enhancements evaluated by single source.

In source [[1], Huawei, HiSi], the following additional enhancements were evaluated with the following observations:

* One symbol PRS:
  + The single PRS symbol transmission achieves almost the same performance with that of multiple PRS symbols for InF-SH scenarios
* PRS punctured by SSB:
  + When the PRS center 20RBs are punctured by SSB, the positioning accuracy is almost not affected
* Angle of arrival with uniform linear array:
  + The positioning accuracy is greatly reduced using legacy AOA reporting
  + The enhanced AOA reporting can approach the UPA positioning accuracy

In source [[4], CATT], the following additional enhancements were evaluated with the following observations:

* CPP (DL-TDOA + DL-CPP, and UL-TDOA + UL-CPP) with double differential techniques can meet the IIoT (InF-HH-2D) horizontal accuracy performance requirements [0.2]m@[90]% even when the network synchronization error is simulated

In source [[9], Sony], the following additional enhancements were evaluated with the following observations:

* Investigation of gNB height on vertical positioning accuracy:
  + The vertical positioning becomes more accurate as the gNB height are getting diverse. In other word, using gNBs with different height can improve the vertical positioning accuracy.
  + In the deployment 3 to 5 and in InF-SH FR2 scenario, the achievable performance is less than 1 m accuracy.
* Bandwidth impact on positioning accuracy:
  + The usage of PRS configuration in a smaller bandwidth degrades the positioning accuracy performance. In the other word, by changing the bandwidth, we can control the positioning accuracy.

In source [[12], Fraunhofer IIS, Fraunhofer HHI], the following additional enhancements were evaluated with the following observations:

* Impact of gNB antenna configuration:
  + Using antennas with higher directivity increase the performance
* Impact UE Tx Power in the presence of interference:
  + A low UE-TX power is sufficient for gNBs with beam forming in InF scenarios
  + When considering interference, the performance with low TX power is only feasible if UEs sharing the same REs use different cyclic shifts for the same SRS root sequence (“cyclic shift multiplex”)
  + For “low power operation” in combination with interference between positioning-SRS resources, cyclic shift enhancements shall be considered in Rel-17.
* Supporting “TX antenna diversity”:
  + Using TX-diversity (4 transmissions at -20dBm from different antennas) shows a similar performance as single port transmission with 0dBm.
  + Support multi-port transmission in Rel-17.
* Uplink beam management evaluation, Tx-Rx Beam pair selection criteria:
  + The beam selection and spatial relationship establishment criteria have major impact on the performance.
* “Narrow” TX beams:
  + When applying narrow beam antenna configuration in FR2 over multiple SRS resources, and in the presence of interference, a degradation in the positioning performance is observed. In case of several TX beams a RTOA selection/combining strategy is required. This algorithm may need further enhancements.

In source [[15], Qualcomm Incorporated], the following additional enhancements were evaluated:

* Kinematic constraint aware
* Enhancement on additional path reporting

In source [[16], vivo], the following additional enhancements were evaluated with the following observations:

* Timing measurement reporting granularity:
  + The minimum Rel.16 granularity of timing measurement reports is enough to avoid degradation in IIoT scenarios and meet positioning requirements.

## Physical Layer Latency Evaluation

### Summary of Physical Layer Latency Analysis for Rel.16 Solutions

The results for the physical layer latency evaluation were presented by 13 out of 17 sources.

It should be noted that the assumptions for the physical layer latency evaluation varies significantly from one source to another. The accurate comparison of the results is problematic.

The summary of the physical layer latency evaluation can be found in Table 5.

Table 5: Physical layer latency evaluation summary.

|  |  |
| --- | --- |
| **Source** | **Physical layer latency range for different methods** |
| Source #1  [[1], Huawei, HiSi] | UE-assisted DL-only positioning: 51.5-66ms (1 samp.), 111.5-126.5ms (4 samp. CSSF = 1), 171.5-186ms (4 samp. CSSF = 2)  UL-only positioning: 6.5-26ms (1 samp.), 66.5-86.5ms (4 samp)  Multi-RTT positioning: 8.5-15ms  UL E-CID positioning: 6-26ms  UE-based DL-only positioning: 51-58.5ms (1 samp.) |
| Source #3  [[3], ZTE] | UE-assisted positioning based on DL-TDOA: 106.23 ms  UE-based positioning based on DL-TDOA: 106.23 ms  UE-assisted positioning based on DL-ECID: 10 ms - 570 ms |
| Source #4  [[4], CATT] | DL-TDOA: 51.5 ms  UL-TDOA: 5 ms |
| Source #6  [[6], Lenovo, Motorola Mobility] | UE-A, DL-TDOA: 17 – 5144 ms  UE-B, DL-TDOA: 17 – 5144 ms |
| Source #7  [[7], OPPO] | UE-A, DL-based: 52 – 54 ms  UE-A, UL-based: 23 ms  UE-B: 44 ms |
| Source #8  [[8], Nokia, Nokia Shanghai Bell] | UE-A, DL-TDOA: 13.07 – 2956.71 ms  UE-A, UL-TDOA: 2.35 – 81925 ms |
| Source #9  [[9], Sony] | DL-TDOA: 56 ms |
| Source #10  [[10], LG Electronics] | DL-TDOA: 20 – 160 ms  UL-TDOA: 1.49 – 4.42 ms  Multi-RTT: 22 – 173 ms  E-CID: 0.84 – 3.5 ms |
| Source #11  [[11], InterDigital, Inc.] | UE-A, DL: 33 ms  UE-B, DL: 22 – 70 ms  UE-A, UL: 12 ms  UE-A, DL+UL: 45 ms |
| Source #14  [[14], Ericsson] | PRS resource with 9 occasions: 33.57 ms (exceeds 10 ms budget) |
| Source #15  [[15], Qualcomm Incorporated] | UE-A, DL, RRC\_CONNECTED: 57 – 823 ms  UE-B, DL, RRC\_INACTIVE: 35.3 – 803.5 ms  UE-B, DL, RRC\_CONNECTED: 46 – 811 ms  UE-B, DL, RRC\_INACTIVE: 8 – 780 ms  UE-A, Multi-RTT, RRC\_CONNECTED: 59 – 823 ms |
| Source #16  [[16], vivo] | UE-A, DL: 64 ms  UE-B, DL: 55.5 - 66 ms  UE-A, UL: 11 - 30.5 ms  UE-A, Multi-RTT: > 94.5 ms |
| Source #17  [[17], Intel Corporation] | DL-TDOA: 4.5 ms + (PRS alignment) 20 ms + (PRS report) 68.5 ms+ L2/L3 components  UL-TDOA: 2.7 ms + L2/L3 components  Multi-RTT: 7.3 ms + (PRS alignment) 20 ms + (PRS report) 68.5 ms+ L2/L3 components |

### Observations / Conclusions on Physical Layer Latency Analysis for Rel.16 Solutions

1. **(On Physical Layer Latency of Rel.16 Solutions)**
   * **The results for the physical layer latency evaluation were presented by [13] out of [17] sources.**
   * **Physical layer latency evaluation results vary among sources, that can be explained by the lack of the agreed by RAN WG1 common reference resource configuration for latency study, lack of common understanding on physical layer latency components as well as by implementation freedom of the Rel.16 NR positioning procedures.**
   * **For UE-assisted positioning solutions, the following common observations can be drawn from the provided evaluation results**
     + **For DL-TDOA / DL-AOD NR positioning techniques, the minimum latency within the range of [50-120] ms is reported by majority of sources. A few sources observed even lower latency values however it does not satisfy 10ms target applicable for selected IIoT use cases.**
     + **For UL-TDOA / UL-AOA NR positioning techniques, the minimum latency within the range of [10-30] ms is reported by majority of sources. A few sources observed latency in the order of [1.5-7] ms that satisfy 10ms target applicable for selected IIoT use cases, however this analysis excluded L2/L3 components within physical layer latency.**
     + **For Multi-RTT NR positioning technique, the physical layer latency is comparable with DL-TDOA/DL-AoD solutions (slightly larger)**
     + **For E-CID positioning technique, results were provided by three sources that reported the following minimum latency ranges [0.84 ms, 6.5 ms and 10ms]**
   * **NR positioning enhancements are needed to achieve target latency in the order of 10 ms for IIoT use cases. The major latency components that require enhancements are**
     + **DL PRS alignment time**
     + **DL PRS measurement and report delay**
     + **Multiple over air transactions and higher layer signaling for UE configuration and UE reporting**

### Summary of Physical Layer Latency Analysis for NR Positioning Enhancements

1. **(On Physical Layer Latency of Enhanced NR Positioning Solutions)**
   * **The following latency reduction enhancements are considered/recommended by companies**
     + **Support of on demand DL PRS transmission (aperiodic DL PRS)**
     + **Measurement gap enhancements**
     + **Enhanced UE DL PRS processing capabilities**
     + **Low layer signaling (DCI/MAC CE) in NR positioning procedures and procedural enhancements**

## Network Efficiency Analysis

TBD

## UE Efficiency Analysis

TBD

# Summary

TBD

# References

|  |  |
| --- | --- |
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