Progress of 3GPP Rel-17 Standards on New Radio (NR) Positioning

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Abstract

Supporting various positioning methods to provide reliable and accurate user equipment (UE) location has always been one of the key features of 3rd generation partnership project (3GPP) standard. Compared with the fourth-generation (4G) system, the usage of wider signal bandwidth and massive antennas in the fifth-generation (5G) New Radio (NR) system provides additional degrees of freedom to enable more accurate UE locations. 3GPP began to study and specify NR radio access technology (RAT)-dependent positioning methods since Release 16 (Rel-16). In this paper, we focus on the recent progress of Rel-17 standards on NR positioning enhancements. In addition, future research work for further positioning enhancement in Rel-18 is discussed.

Keywords

3rd Generation Partnership Project (3GPP), New Radio (NR), Positioning, Timing delay, On-demand positioning reference signal (PRS), Non-Line of Sight (NLOS), Downlink-Angle of Departure (DL-AoD), Uplink-TDOA (UL-TDOA), Uplink-Angle of Arrival (UL-AoA).[1]

1. Introduction

Supporting various positioning methods to provide reliable and accurate user equipment (UE) location has always been one of the key features of 3rd generation partnership project (3GPP) standard. Compared with the fourth generation (4G) system, 3GPP fifth generation (5G) New Radio (NR) supports wider signal bandwidth (e.g., up to 100 MHz for frequency band below 6GHz, and 400 MHz for frequency band above 6GHz), which provides additional degrees of freedom and brings new performance bounds for UE location for the positioning technologies utilizing timing measurements. Furthermore, 5G NR massive antenna systems provide additional degrees of freedom to enable more accurate UE locations by exploiting spatial and angular domain information of radio signal propagation channels in combination with time measurements.

Since Release 16 (Rel-16) in 2018, 3GPP began to study and specify NR radio access technology (RAT)-dependent positioning methods, including the positioning reference signals, measurements, procedures, and related signalings. The target horizontal positioning requirements for commercial use cases defined for Rel-16 were < 3 meter (80%) for indoor scenarios and < 10 meter (80%) for outdoor scenarios ([1]). NR positioning methods specified in Rel-16 include multiple cell-round trip time (Multi-RTT), downlink-time difference of arrival (DL-TDOA), downlink-angle of departure (DL-AoD), uplink-TDOA (UL-TDOA), and uplink-Angle of Arrival (UL-AoA) [2]).

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3GPP Rel-17 NR positioning enhancement study item was finished in 2020, targeting higher positioning accuracy and lower latency than Rel-16, high integrity and reliability requirements for supporting new applications and industry verticals for 5G. The target horizontal positioning requirements defined for Rel-17 were < 1 meter (90% of UEs) for commercial use cases and < 0.2 meter (90% of UEs) for industrial internet of things (IIoT) use cases [3]. After the complication of the study item, 3GPP has been working on Rel-17 NR positioning enhancement work item since 2021, which targets to specify solutions to enable RAT dependent and RAT independent NR positioning enhancements for improving positioning accuracy, latency, network and/or device efficiency [4]. The objectives of this work item are specifying methods, measurements, signalling, and procedures for the following aspects: a) mitigating UE and/or gNB reception/ transmission (Rx/Tx) timing delays; b) improving the accuracy of UL-AoA; c) improving the accuracy of DL-AoD; d) improving positioning latency of the Rel-16 NR positioning methods; e) supporting positioning for UEs in radio resource control-INACTIVE (RRC_INACTIVE) state; f) supporting on-demand transmission and reception of DL positioning reference signal (PRS); g) studying necessity of multipath/Non-Line of Sight (NLOS) mitigation method; h) supporting global navigation satellite system (GNSS) positioning integrity determination and enhancements of assisted-GNSS (A-GNSS) positioning (BeiDou navigation satellite system and Navigation with Indian constellation to NR).

The rest of this paper is organized as follows. In Section II, the progress of NR Rel-17 positioning enhancement work item is presented. In Section III, future research work for 3GPP Rel-18 positioning enhancement is discussed. Finally, Section VI concludes the paper.

2. Progress of NR Rel-17 positioning

The progress of NR Rel-17 positioning enhancement work item is presented from the following seven aspects.

2.1. Mitigation of UE Rx/Tx and/or gNB Rx/Tx timing delays

From a signal transmission perspective, there will be a timing delay from the time when the digital signal is generated at the baseband to the time when the radio frequency signal is transmitted from the Tx antenna. For supporting positioning, the UE and the transmission and reception (TRP) may implement an internal calibration/compensation of the Tx timing delay for the transmission of the DL PRS/UL sounding reference signal (SRS), which may also include the calibration/compensation of the relative timing delay between different radio frequency chains in the same UE/TRP. The compensation may also possibly consider the offset of the Tx antenna phase center to the physical antenna center. However, the calibration may not be perfect. The remaining Tx timing delay after the calibration or the un-calibrated Tx timing delay is defined as the Tx timing error. Similarly, from a signal reception perspective, the remaining Rx time delay after the calibration, or the un-calibrated Rx time delay is defined as Rx timing error [5].

As an example, Figure 1 shows the UE Rx/TRP Tx timing delays for DL-PRS transmission and reception when a TRP (named TRP1) sends DL-PRS to a UE, where the Tx timing delay in the TRP radio frequency Tx chain with index=i is denoted as TD_{Txi}, the propagation time in air between the antenna of the TRP and the antenna of the UE is denoted as $Prop_{TRP\text{-}UE}$, the Rx timing delay in the UE radio frequency Rx chain with index=m is denoted as TD_{Rxm}. Therefore, the time of arrival (TOA) measured by the UE via DL-PRS between the baseband of the TRP1 and the baseband of UE is:

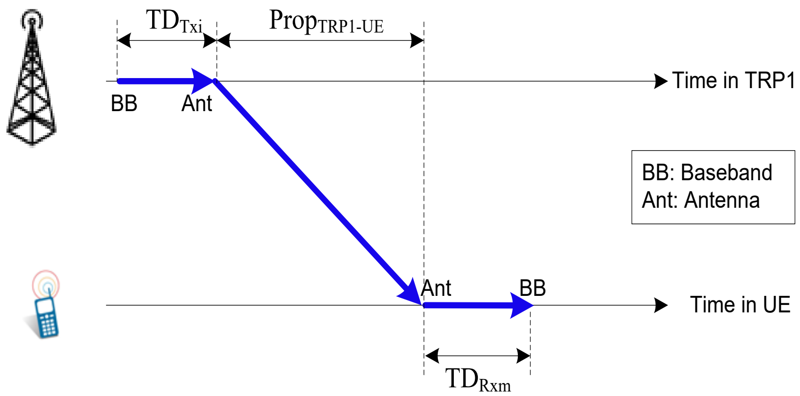

Figure 1: UE/TRP Rx/Tx timing delays for DL-PRS Tx and Rx

$$ToA_{TRP1\text{-}UE} = TD_{Txi} + Prop_{TRP1\text{-}UE} + TD_{Rxm}, \quad (1)$$

The real TOA between TRP1 and UE for positioning purpose should be only $Prop_{TRP1\text{-}UE}$, and the residual error of TOA is TD_{Txi}+ TD_{Rxm}.

Usually, TD_{Txi} and TD_{Rxm} are calibrated in advance to minimize the influent of such timing delays on positioning accuracy. The remaining timing delay errors after the calibration are called the timing errors in Rel-17 positioning enhancement.

The values of the UE/TRP Rx/Tx timing error after the coarse calibration may be in the order of several nanoseconds (ns) or more. Considering that the 1ns timing error will lead to the 30 centimeters distance error, and Rel-17 target positioning requirements for IIoT use cases is 20 centimeters in horizontal position accuracy, the impact of timing errors on positioning should be eliminated to achieve Rel-17 sub-meter level positioning accuracy. Figure 2 illustrates an example of the performance degradation due to UE Rx/TRP Tx timing errors for DL-TDOA positioning method for an indoor factory with sparse clutter and high base station height (InF-SH) scenario ([3]), where absolute delay is included in the channel model and makes the channel model more accurate for positioning performance evaluation. As shown in Figure 2, the horizontal positioning error (x) is degraded from 0.128 meters @90% cumulative distribution function (CDF) point when there are no UE/gNB Rx/Tx timing errors to 3.411 meters @90% CDF point when UE/gNB Rx/Tx timing errors are modeled as [-2σ, 2σ] truncated Gauss distribution with σ = 5ns.

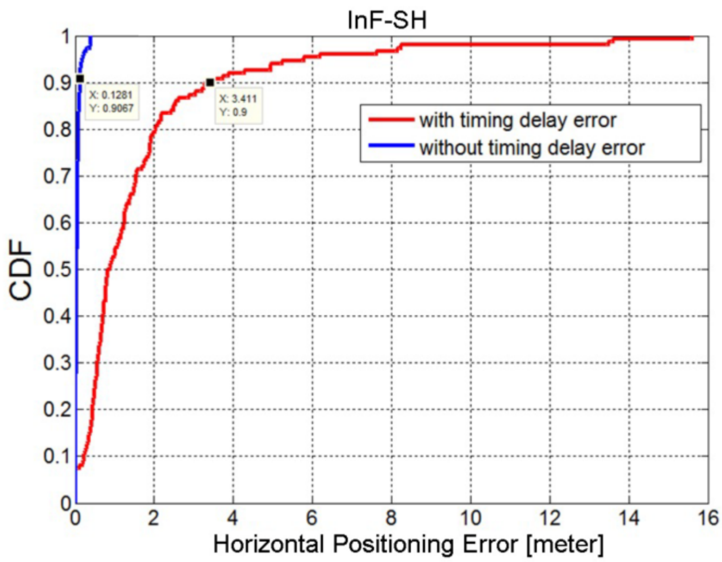

Figure 2: Performance degradation due to UE Rx/TRP Tx timing delay

The current status of NR Rel-17 on UE and/or gNB Rx/Tx timing delays until May 27th, 2021 is given in the following.

In NR Rel-17, a UE/TRP Tx timing error group (TEG) is defined to be associated with the transmissions of one or more UL SRS/DL PRS resources for the positioning purpose, which has the Tx timing errors within a certain margin. A UE/TRP Rx TEG is associated with one or more DL/UL measurements, which have the Rx timing errors within a certain margin. A UE/TRP Reception & Transmission TEG is associated with one or more UE/gNB Rx-Tx time difference measurements and one or more UL SRS/DL PRS resources for the positioning purpose, which have the 'Rx timing errors + Tx timing errors' within a certain margin.

The following two schemes are discussed in 3GPP to mitigate the influent of Rx/Tx timing errors as follows [6].

- Scheme 1: Mitigating UE/TRP Rx/Tx timing errors based on the compensations of Rx/Tx timing errors in the measurements.
- Scheme 2: Mitigating UE/TRP Rx/Tx timing errors based on the use of the reference devices.

For scheme 1, 3GPP has decided to support the following enhancements:

- Support a UE/TRP to provide the association information of reference signal time difference measurements with UE Rx TEGs or DL PRS resources with Tx TEGs to the location management function (LMF) for DL-TDOA positioning method.
- Support a TRP/UE to provide the association information of RTOA measurements with TRP Rx TEGs or UL SRS resources for positioning with Tx TEGs to the LMF for UL-TDOA positioning method.

For scheme 2, 3GPP radio access network (RAN) work group#1 (RAN1) has reached the following agreements:

- Study specification impact to RAN work group#2 (RAN2)/RAN work group#3 (RAN3) for enabling a positioning reference unit with known location to support mitigation of timing errors.
- Study specification impact to RAN2/RAN3 for enabling PRUs with known location to support mitigation of timing errors.

Until May 27th, 2021, the remaining issues and potential solutions on UE and/or gNB Rx/Tx timing delays are discussed in the following

For DL positioning methods with UE-assisted solutions, the following two methods are suggested to be further studied to help LMF eliminate the influence of timing errors of TRPs and UE:

- Method 1: Provide LMF the Tx timing errors per Tx TEG.
- Method 2: Provide LMF the Tx timing error differences between Tx TEGs.

For Scheme 2, a reference device with a known location is enabled to support the mitigation of UE/TRP Rx/Tx timing errors. NR Rel-17 may support reporting the location coordinate information of reference UE from UE to LMF. There are three candidate methods to obtain the location coordinates of a reference device.

- Method 1: The reference device is placed in a known position.
- Method 2: The location of reference UE is calculated by RAT-independent positioning scheme (such as A-GNSS etc.).
- Method 3: The reference device is placed at the location of a TRP with a known position.

2.2. Accuracy improvement of UL-AoA

UL-AoA is a positioning method based on UL AoA measurement, which highly relies on the accuracy of angle measurement, which is impacted by gNB and TRP non-ideal factors. NR Rel-17 study item has studied scenario, benefits, and methods for improving the accuracy of the UL-AoA and recommended UL-AoA for normative work for network-based positioning solutions.

The current status of NR Rel-17 on UL-AoA until May 27th, 2021 is given in the following.

In the ongoing Rel-17 positioning enhancements work item [5], the following enhancements of UL-AoA have been agreed:

- Support the z-axis of local coordinate system (LCS) defined along the linear array axis to enhance signaling of UL-AoA measurement report in case of a linear array, where gNB reports only the zenith-AoA relative to z-axis in the LCS, and the LCS-to-global coordinate system (GCS) translation function is used to set up the specific z-axis direction.

- Support at least the following additional assistance signaling from LMF to gNB/TRP to facilitate UL measurements of UL-AoA: indication of expected azimuth-AoA/ zenith-AoA value and uncertainty.
- Support reporting of M > 1 UL-AoA (azimuth-AoA/ zenith-AoA) measurement values associated with the first arrival path and corresponding to the same timestamp by gNB to the LMF.

For aiding UE/gNB to detect the DL/UL positioning reference signals, NR Rel-17 supports the LMF to provide the UE/gNB with the search time window information. In general, the search windows for the reception of DL/UL signals are determined based on the signal propagation time from the transmitter to the receiver, which is estimated based on the known position of the TRPs and the approximate position of the UE, the uncertainty of the time offset between the transmitter and the receiver, and the uncertainty of the UE location.

The time-search window information is helpful for timing-related positioning measurements, but may not be useful for angular-related positioning measurements, since it does not provide the information related to the direction of incoming signals.

There is another approach for aiding the UE/gNB to obtain both timing-related measurements and angular-related measurements. In this approach, the LMF will directly provide the UE/gNB with the approximate UE's location as well as the uncertain of the UE's location. Then, the UE/gNB can determine the search window for timing-related measurements but also the angular-related measurements by themselves. This approach has the following advantages:

- Reducing the search window for all positioning measurements, i.e., not limited to timing-related measurements as existing approach.
- Helping the elimination of inaccurate angular measurements, under a multipath environment, the direction of multipath signals can be completely different from the LOS direction.
- Providing the UE's approximate location to UE/gNB, allow the receiver to avoid the false angular measurements due to multipath signals.

In Rel-17, the search window for UL-AoA measurements is provided by the expected azimuth-AoA/ zenith-AoA value and uncertainty range(s) from LMF to gNB/TRP. The search windows for TDOA and AoA are shown in Figure 3.

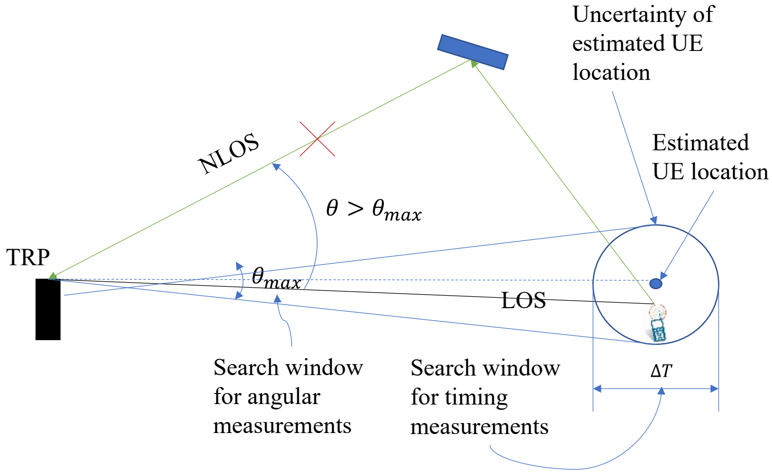

Figure 3: The search windows for TDOA and AoA

Until May 27th, 2021, the remaining issue for UL-AoA is the calibration of gNB angle error. In the following, the impact of TRP non-ideal factors is discussed. When a TRP receives the positioning reference signal transmitted from a UE, the signal arrives at the baseband through the antenna array and radio frequency chains. TRP estimates the UL AoAs based on the spatial signals obtained from all antenna elements of the receiving antenna array.

The Rx antenna array is nominally assumed to be composed of uniformly spaced identical elements and each radio frequency channel is assumed to perform identically. If the characteristics of all antenna elements of the antenna array and radio frequency chains were ideal, UL AoA can be obtained accurately with a high-resolution algorithm. However, in practical engineering applications, the antenna array and radio frequency channels have non-ideal factors, such as the radio frequency radiation pattern error of antenna elements, the location error of antenna elements, the mutual coupling of array elements, and the amplitude and phase error of radio frequency channel. These non-ideal factors of the antenna array and radio frequency channels introduce disturbance to the steering matrix used for the UL AoA estimation.

In the following, a calibration method with reference UE is introduced. The antenna array and radio frequency channels of TRPs may be calibrated with the internal and/or the external calibration methods to enhance UL-AoA accuracy:

- Internal calibration method: In this method, the calibration signal is either directly sent to the radio frequency RX channels or to the antenna elements. If the calibration signal is directly sent to the radio frequency RX channels, only radio frequency RX channels can be calibrated. If the calibration signal is received by an antenna element and then enters the radio frequency RX channel, the radio frequency RX channel and the antenna element can be calibrated together. The issue of the method is that it cannot calibrate the mutual coupling of antenna elements, which has a more obvious effect on the frequency band above 6 GHz.
- External calibration method: This method uses external equipment for offline calibration, and it is usually carried out in an anechoic chamber. The issue of the method is that it cannot track the changes of non-ideal factors of the antenna array and radio frequency chains with the environment, temperature and time.

In order to enhance UL-AoA measurement accuracy, a method that uses a reference UE with known location to assist TRP Rx beam calibration was proposed [7]. This method consists of two stages of calibration:

- Static calibration: Static calibration can be seen as an initial antenna array calibration, in which a reference UE is placed at test points with known locations in turn, and sends UL SRS. The reference UE also reports its location coordinates to LMF. LMF uses the calculated, actual AoA angle from each test point based on its known location coordinates to calibrate AoA measured provided by the TRP. A testing scenario is shown in Figure 4.
- Dynamic calibration: After initial calibration, TRP Rx beam direction may be drifted due to the changes of the environment, temperature, etc. For dynamic calibration of an antenna array, we may use a UE located at a single test point to track the drift of Rx beam directions of the TRPs.

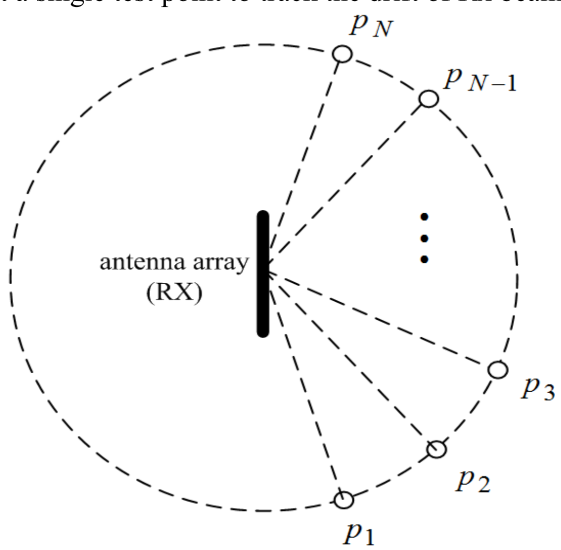

Figure 4: Test points for static calibration

2.3. Accuracy improvement of DL-AoD

DL-AoD is a positioning method based on DL AoD measurement, which highly relies on the accuracy of reference signal received power (RSRP) measurement in UE and TRP non-ideal factors.

For DL-AoD positioning, UE measures the DL PRS transmitted from different TRPs according to the configuration provided by LMF and reports DL RSRP as measurement results to LMF. In addition, gNB would provide the beam information (azimuth angle and elevation angle) related to each DL PRS to LMF. Based on the reported RSRP measurements from UE and corresponding DL PRS beam information from TRPs, the DL-AoDs between UE and the TRPs could be determined.

Until May 27th, 2021, NR Rel-17 on DL- AoD has agreed to support gNB providing the beam/antenna information to the LMF. And the following issues would be further studied:

- Enable the UE to measure and report (for UE-assisted) PRS RSRP of the first arriving path.
- The number of RSRP measurements reported per TRP (e.g. increase the number of measurements).
- Enhancing the signaling to UE for PRS measurement and reporting (e.g. adjacent beam reporting or PRS measurement restriction).
- Support DL AoD measurements with an expected uncertainty window.
- Support two-stage PRS beam sweeping (coarse beam sweeping and fine beam sweeping) to reduce measurement complexity and latency.
- gNB reports the antenna configuration (at least includes the number of antenna elements and antenna spacing) or a mapping of angle and beam gains for each of the PRS resources to LMF.

Until May 27th, 2021, the remaining issues and potential solutions on DL-AoD are discussed in the following.

The DL-AoD positioning accuracy depends on the estimation accuracy of AoD [8]. The beam pattern of a PRS resource includes the main lobe and several side lobes. There would be some overlap between PRS resources with adjacent Tx beams. By providing the RSRP measurements of those PRS resources with Tx beams next to that of the PRS resource with the largest RSRP (defined as PRS resources with adjacent beams), finer AoD would be calculated using certain interpolation methods. To guarantee UE reporting RSRP measurements of adjacent beams, LMF may configure several adjacent DL PRS resources per TRP, to allow a UE to report RSRP measurements of all these PRS resources. Or, a UE can be requested to measure and report on specific PRS resources. However, configuring these adjacent DL PRS resources with proper beam directions or restricting UE measurements depends on the knowledge of the coarse position of the UE. Another alternative is to inform the azimuth angle and elevation angle of each PRS resource to the UE, as each gNB has its adjacent beam information, this information could be sent to LMF and then configured in the DL assistance data.

As mentioned above, in Rel-16, only the azimuth angle and elevation angle of each PRS resource are used to indicate the beam information. To present the details of the beam of PRS resource more accurately, more information is needed to describe each beam. In addition to the number of antenna elements, analog beamforming vector and digital beamforming vector, such as codebook used for precoding could also be provided by TRP. Then LMF would construct the ideal DL PRS beam distribution. Combined with RSRP measurement from UE, the accuracy of DL-AoD can be effectively improved.

For a UE with multiple Rx beams, Rx beam training is usually employed to determine the optimum Rx beam for the reception of DL PRS resources. The Rx beam training procedure causes additional positioning latency. As an enhancement, it is beneficial to introduce an uncertainty window for DL AoD to reduce Rx beam training. UE would only try those Rx filters within the uncertainty window to determine an optimized Rx beam. From the gNB perspective, the uncertainty window could be the expected DL AoD/ZoD value. From the UE perspective, the expected DL AoA/ZoA value could be used. In the LOS scenario, these two options are equivalent. These expected angles should be defined with a reference direction. However, some UEs may not know their orientations. If the expected DL AoD/ZoD value or DL AoA/ZoA value are defined in GCS or LCS, these UEs may not be able to use the angle information. Since reference signals (e.g., synchronization signal block, DL PRS in Rel-16) are used to provide the Rx beam information, it is reasonable to use the boresight direction of DL reference signal or UL reference signal as the reference direction.

2.4. NLOS/Multi-path mitigation

The components of timing delays from NLOS and multipath introduce significant errors to time measurements and degrade the final positioning performance greatly.

In NR Rel-17 study item, the impact of NLOS/multipath on NR positioning accuracy was investigated. Various resolutions for NLOS/multipath mitigation were proposed, including LOS/NLOS identification, outlier rejection, and NLOS mitigation based on triangle inequality algorithms to improve performance of positioning accuracy. NR Rel-17 work item will further study and specify, if agreed, the enhancements of information reporting from UE and gNB for multipath/NLOS mitigation. In RAN1#105-e meeting until May 27th, 2021, it was agreed to study the reporting of LOS/NLOS indicators and multipath information for DL, UL, and DL+UL positioning [9].

In this section, an algorithm is proposed to mitigate the influence of NLOS and multipath [10] by reporting the LOS/NLOS identification information, which is defined as a function of the Rician factor in the time domain, the variance of channel frequency response (CFR) in the frequency domain, and the energy or the angle consistency in the spatial domain. The LOS/NLOS identification information can be used to identify and select LOS links between the TRPs and UE for mitigating the influence of NLOS and multipath to obtain a more accurate location of UE.

The proposed algorithm consists of the following 6 steps for deriving the LOS/NLOS identification of each TRP (Note: UE-assisted DL positioning is used here as an example for explaining the algorithm. The same algorithm can be also used for UL positioning):

Step 1: A UE calculates the Rician K factor in the time domain according to channel impulse response from the received reference signal.

Step 2: The UE evaluates the timing delay of the first detected path and mitigates the influence of the timing delay difference by post-compensation of the received reference signal with the use of cyclic shift of received signal (or channel impulse response) in the time domain, or phase compensation of CFR in the frequency domain.

Step 3: The UE calculates channel variance in the frequency domain based on CFR of post-compensated signal from step 2.

$$\sigma_i^2 = \frac{\sum_{k=1}^{N}(H_i(k) - \overline{H}_i)^2}{N}, \quad (2)$$

where $H_i(k)$ denotes the normalized CFR at the k-th subcarrier (1<=k<=N) for i-th TRP under the constraint that the total power of the channel impulse response is normalized to unity, $\overline{H}_i$ is the mean value of CFR of N subcarriers for i-th TRP, and N is the number of used subcarriers of the DL-PRS resource.

Step 4: The UE normalizes Rician K factor in time domain and the variance in frequency domain, e.g., the reciprocal of variance, $1/\sigma_i^2$ for i-th TRP, in order to follow the trend of Rician K factor.

Step 5: The UE generates LOS/NLOS identification information by the soft decision and/or hard decision, as described before, and reports the information to the LMF.

The soft decision of LOS/NLOS identification information (called $\mathrm{Confidence}_i$) of i-th TRP is based on the Rician K factor from Step 1 and reciprocal of variance from Step 4, which is defined in the following form:

$$Confidence_i = a_i * K_i + b_i * L_i, \quad (3)$$

where a_i and b_i denote the weight factor of Rician K factor and reciprocal of variance from i-th TRP with $a_i+b_i=1$, respectively; K_i and L_i are normalized Rician K factor and normalized reciprocal of variance (e.g., $L_i = 1/\sigma_i^2$), inter-TRPs respectively, and K_i and L_i are in the range of 0 to 1.

The hard decision of LOS/NLOS identification information ($\mathrm{Confidence}_i$) is defined in the following form:

$$Confidence_i = \begin{cases} 1, & K_i > TH_K \ \& \ L_i > TH_L \\ 0, & others \end{cases}, \quad (4)$$

where TH_K and TH_L are the thresholds of Rician K factor and reciprocal of variance, respectively.

Step 6: The LMF selects measurements with no or less effect of NLOS and multipath according to the LOS/NLOS identification information (e.g., with the highest LOS/NLOS identification information) and calculates the location of UE (e.g., together with minimum residual error method).

The effectiveness of the above algorithm for LOS/NLOS identification is evaluated through numerical simulation for InF-SH and indoor factory with dense clutter and high base station height (InF-DH) scenarios with the simulation assumptions given in Table 1[10]. The LOS/NLOS identification probability (ρ) is defined as $\rho=\frac{X1}{Y1}*100\%$, where X1 is the detected number of LOS links and Y1 is the number of links used for identification. In CASE 1 (Baseline), the detected TRPs with the highest Y1 RSRP are chosen. In CASE 2, the combination of variance and Rician K factor from the proposed algorithm is used. From simulation results in

Table 2, it is shown that LOS/NLOS identification probability (ρ) in CASE 2 is higher than ρ in CASE 1 for both InF-SH and InF-DH scenarios, which shows that the proposed algorithm can achieve a higher LOS/NLOS identification probability compared to baseline under the given simulation assumptions.

Table 1

Simulation assumptions

Parameters	Values
Scenarios	InF-SH, InF-DH
Bandwidth	100MHz
Total number of TRP	18
PRS PRB Number	268
Comb factor	6
Carrier Frequency	3.5 GHz
Subcarrier Spacing	30 kHz

Table 2

Simulation result of LOS/NLOS identification probability (**ρ**) with **Y1**=3

Scenarios	Identification Probability	
	CASE 1	CASE 2
InF-SH	84.33%	100%
InF-DH	43.67%	97.67%

2.5. On-demand PRS

The ability to enable DL-PRS when needed implies that DL-PRS can be disabled when there is no UE to be positioning. On-demand PRS functionality is deemed beneficial for the improvement of efficiency. UE-initiated on-demand PRS request is enabled by the UE request triggering a request from the LMF, and the actual PRS changes are requested by the LMF irrespective of whether the procedure is UE-initiated or LMF-initiated.

- The procedure(s) for on-demand DL-PRS should support at least the following functionality agreed in 3GPP.
- Providing the requested on-demand DL-PRS configuration information from an LMF to the gNB (e.g., explicit parameter or identifier of a predefined DL-PRS configuration), and confirmation of the request by the gNB.
- Provision of (possible/allowed) on-demand DL-PRS configurations that the gNB can support from a gNB to an LMF.
- TRP capability transfer (e.g., whether the RAN node supports the reconfiguration of DL-PRS, etc.).

The network can signal predefined PRS configurations to the UE and the UE can select one to request. A new LPP assistance data IE can contain a set of possible on-demand DL-PRS configurations, where each on-demand DL-PRS configuration has an associated identifier.

This new LPP assistance data IE can be included in an LPP Provide Assistance Data message and/or a new posSIB.

The following issue should be resolved in order to support UE-initiated on-demand PRS [11]: What can be requested by UE-initiated on-demand PRS.

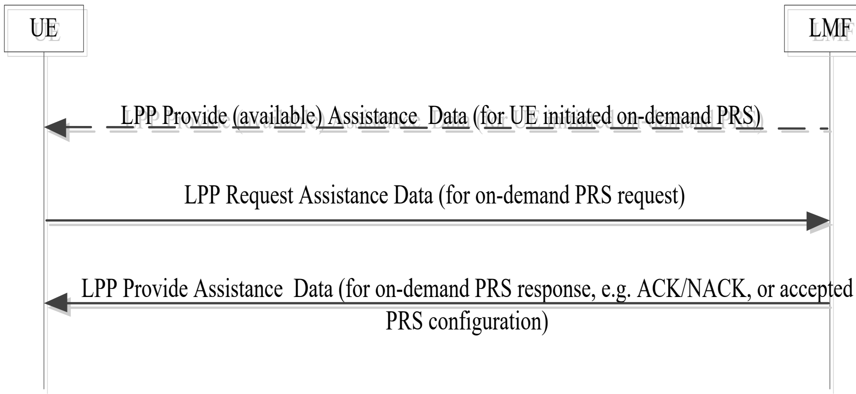

Figure 5: UE initiated on-demand PRS procedure

Figure 5 shows UE initiated on-demand PRS procedure. From the performance improvement perspective, UE can provide its recommend PRS configuration to LMF, i.e., turn on/off PRS, PRS periodicity, PRS duration. UE may provide the following information to the gNB and/or LMF when the UE sends an on-demand PRS request to the LMF:

- DL measurements available in UE, which may include SS-RSRP, channel state information-RSRP, etc., measured from the serving gNB and neighboring gNBs.
- The requested DL PRS resources in the time and frequency domain, and/or the quality of service (QoS) parameters related to target positioning performance (e.g., the start time, duration, periodicity, the repetition number of PRS resources, etc.) to help the gNBs to allocate DL PRS resources properly.

There are some challenges of management of on-demand UEs for network, such as 1) on-demand PRS requests may be initiated from many UEs, which will bring large positioning latency or traffic jam in the network; 2) the short interval between two consecutive on-demand PRS request from a UE may bring consecutive failures if not controlled by the network. So both the network and UEs should take action to face the challenges, such as 1) network follows the procedure as above, and provides the available DL-PRS resource information to the candidate UEs. Only the UEs that have received the available DL-PRS information can request PRS configuration based on the available PRS provided information provided by LMF; 2) LMF controls the numbers of on-demand requests in one positioning session and also the interval between two consecutive on-demand requests per UE.

The following two issues should be resolved in order to support LMF-initiated on-demand PRS.

- Issue 1: What can be requested by LMF initiated on-demand PRS.
- Issue 2: When to initiate the on-demand PRS request by LMF.

For Issue 1, the following information can be included within the LMF-initiated on-demand PRS request:

- The request to turn on/off the PRS transmission;
- The PRS configuration, e.g., PRS type, DL PRS resources in the time and frequency domain (PRS periodic, PRS duration, etc.), and/or the QoS parameters related to target positioning performance (e.g., the start time, duration, periodicity, and repetition number of PRS resources, etc.) to help the gNB to allocate DL PRS resources properly.

For Issue 2, when LMF initiates the on-demand PRS should be up to network implementation, e.g., when LMF obtain the assistance information from UE, or when the PRS resources configured by NG-RAN node cannot guarantee the QoS, or when LMF finds the PRS resources configured by NG-RAN node not available. Additionally, UE may provide assistance information to LMF, e.g., beam index, channel state information, radio resource management (RRM) measurement results, via LPP message to improve the performance.

2.6. Latency Reduction

The target Rel-17 latency requirement is less than 100 milliseconds, and in the order of 10 milliseconds for some IIoT use cases [3]. To support the target requirement, latency reductions related to the request and response of location measurements or location estimate and positioning assistance data are included in Rel-17 work item. M-sample PRS processing is corresponding to measurements performed within M instances of the DL PRS resource set on a PRS resource. In RAN1#105-e meeting until May 27th, 2021, it was agreed that 1<=M<4 was beneficial from a physical layer perspective for latency reduction [9].

For latency reduction, there are three remaining issues:

- Issue 1: Latency reduction by scheduled location time.
- Issue 2: Latency reduction on measurement reporting.
- Issue 3: Latency reduction on measurement gap (MG) configuration.

For Issue 1, in some scenarios, the UE, the location service client, or the application functions that is requesting the location of a target UE, may know the time at which the location should be obtained. So the known time, referred to as a scheduled location time, can be provided in advance to reduce the effective latency in providing location results [12]. For latency reduction in UE-assisted mode, when LMF is required to support the scheduled location time, it may schedule the providing assistant data and requesting location information ahead of the scheduled location time with the time budget, so UE may report the measurement in time. For latency reduction in UE-based mode, the latency of location calculation in the UE side is not clear for LMF because different UEs have different latency of location calculation. It’s hard for LMF to get the accurate time budget to schedule the location time. So LMF may forward the scheduled location time to UE when UE is responsible for calculating the location information.

For Issue 2, there is the latency for a UE to report its measurement results to LMF for calculating UE location for UE-assisted DL positioning. After performing location measurement, the UE needs to go through the following procedures for reporting measurement: a) UE prepares scheduling request, waits for scheduling request occasion and sends out it to request PUSCH resource; b) The serving gNB decodes scheduling request, prepares and sends UL grant to the UE; and c) UE decodes UL grant and sends the DL measurement report to LMF. To reduce UE reporting delay, it would be better that before the measurement gap, UE sends out the scheduling request to request PUSCH resource for measurement reporting, and then gNB schedules the PUSCH resource for UE to report the measurement result after the measurement gap. However, the reporting event for a location measurement from a UE to LMF is transparent to the serving gNB. Because the serving gNB does not know when the UE will transmit the location measurement report, the PUSCH resource could mistakenly be scheduled before the measurement gap. To resolve this issue, LMF can first inform the serving gNB when the UE is expected to report location measurement, then the serving gNB sends the UL grant to UE prior to the measurement gap, which schedules the UL resource to UE in the proper time after the measurement gap.

For Issue 3, only periodic PRS and periodic MG is supported in Rel-16. Rel-16 MG repetition period is from 20ms to 160ms, and MG length is from 1.5ms to 6ms. Total positioning latency will rely on MG length and MG repetition period. Using aperiodic PRS is an effective method to achieve low positioning latency in Rel-17 [13]. For reducing the measurement latency and support aperiodic PRS in Rel-17, an aperiodic MG should be introduced, where MG repetition period can be set to 0 and MG length can be set to be the total length of DL PRS resource set. The configuration of the aperiodic MG can be informed to UE by explicit signaling or implicit method.

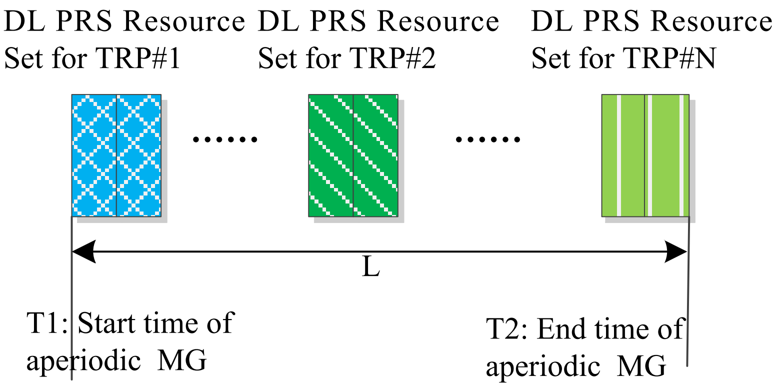

Figure 6: Illustration of aperiodic MG

Figure 6 shows an approach for configuring an aperiodic MG for the reception of DL PRS from N TRPs, where *T1(MG)*, *T2(MG)* and *L* denote the start time, end time, and duration of the aperiodic MG, respectively. The value of *T1, T2*, and *L* can be informed to UE by signaling. The relationship of *T1, T2*, and *L* is as follows:

$$T1(MG) = min\{T1\ (TRP\#1), \ldots, T1(TRP\#N)\}, \tag{5}$$

$$T2(MG) = max\{T2(TRP\#1),\ldots,T2(TRP\#N)\}, \tag{6}$$

$$L=T2(MG)\text{-}T1(MG), \tag{7}$$

where *T1(TRP#k)* and *T2(TRP#k)* represent the start time and end time of aperiodic MG for *TRP#k*, respectively.

2.7. GNSS positioning integrity

The ability to navigate safely means users must trust their estimated position with a high degree of confidence. The trustworthiness of location estimation is the scope of positioning integrity.

Positioning integrity is defined as follows: A measure of the trust in the accuracy of the position-related data provided by the positioning system and the ability to provide timely and valid warnings to the location service client when the positioning system does not fulfill the condition for intended operation [14].

LPP signaling works for delivering the key performance indicators and integrity results, the integrity assistance information to the UE and the integrity information related to the GNSS positioning measurements from the UE to the LMF. The types of feared events will be considered for implementing positioning integrity using A-GNSS within UE-based or UE-assisted positioning integrity mode. So assistance information will be further discussed in 3GPP Rel-17 WI to mitigate feared events which includes:

- Feared events in the GNSS Assistance Data: Incorrect computation of the GNSS Assistance Data, e.g. software bug, corrupt or lost data; and External feared event impacting the GNSS Assistance Data, e.g. satellite, atmospheric or local environment feared events (Category 3) impacting the GNSS reference stations in the GNSS correction provider's network.
- GNSS feared events: Satellite feared events, e.g. bad signal-in-space or bad broadcast navigation data; Atmospheric feared events, and Local Environment feared events, e.g. Multipath, Spoofing, Interference
- UE feared events: GNSS receiver measurement error.

Access and mobility management function sends the location service request together with the integrity service request to LMF. Integrity requirement in LPP Request Location Information will include alarm limit, integrity risk and time to alarm. According to the existing location service request which carries location service requested QoS information (e.g., accuracy, response time, location service QoS class), it's better for location service client to make the decision if the system available or not by itself with protection level report to location service client from LMF. In Rel-17, the signalling framework for supporting positioning integrity are expected to be as follows: UE may send the integrity monitor/measurement results in UE-assisted mode, or send calculated protection level in UE-based mode.

3. Future work for 3GPP REL-18

In our view, NR positioning further enhancements for Rel-18 may consider the following aspects [14] [15]: a) satisfy more ambitious system requirements for positioning accuracy (centimeter-level), latency (millisecond-level) and availability in many verticals; b) extend the support of NR positioning to reduced capability devices/low-cost devices, and support low power high accuracy positioning; c) support NR positioning over proximity communication port 5 sidelink for indoor and vehicle-to-everything scenarios; d) support NR positioning for high-speed trains especially under the tunnel environment. For the improvement to positioning accuracy in Rel-18, NR carrier phase positioning method is a good candidate, which can be supported by reusing the Rel-16 reference signals and procedures with introducing new carrier phase measurements.

4. Conclusion

In this paper, we first discussed the overall progress of 3GPP NR positioning since Rel-16. Then we presented the recent progress of 3GPP Rel-17 standards on NR positioning enhancements. Finally, we provided our view on future research work for 3GPP Rel-18 further positioning enhancement. It is expected that 5G NR positioning will play an increasingly important role in 5G standards.

5. Abbreviations

Abbreviations and Acronyms	Full name
3GPP	3rd Generation Partnership Project
4G	4th-Generation
5G	5th-Generation
AOA	Angle of Arrival
CDF	Cumulative Distribution Function
CFR	Channel Frequency Response
DL-AoD	Downlink-Angle of Departure
DL-TDOA	Downlink-Time Difference of Arrival
gNB	next Generation Node B
GCS	Global Coordinate System
GNSS	Global Navigation Satellite System
IIoT	Industrial Internet of Things
InF-SH	Indoor Factory Sparse Hall
InF-DH	Indoor Factory Dense Hall
LCS	Local Coordinate System
LMF	Location Management Function
LOS	Line of Sight
MG	Measurement Gap
Multi-RTT	Multiple cell-Round Trip Time
NLOS	Non-Line of Sight
PUSCH	Physical Uplink Share Channel
QoS	Quality of Service

PRS	Positioning Reference Signal
RAN	Radio Access Network
RAT	Radio Access Technology
Rel-16	Release 16
Rel-17	Release 17
Rel-18	Release 18
RSRP	Reference Signal Received Power
Rx	Reception
SRS	Sounding Reference Signal
Tx	Transmission
UE	User Equipment
UL-TDOA	Uplink-Time Difference of Arrival
UL-AoA	Uplink-Angle of Arrival

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