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**Agenda Item:**  **9.4.1.9**

**Source: Intel Corporation, CATT, Ericsson**

**Title:** **WI summary for WI Core part: Expanded and Improved NR Positioning**

**WI code(s): NR\_pos\_enh2**

**leading WG: RAN1**

**Release: Rel-18**

### 1 Introduction

The Release 18 work item (WI) on expanded and improved NR positioning introduced multiple features to ***expand*** the scope of NR positioning and to enable various ***improvements*** to support of high accuracy positioning in NR systems [1].

The ***expansion*** of the scope of NR positioning involved support of Sidelink (SL) positioning for which the initial target scenarios, targeting V2X, public safety, IIoT, and commercial use-cases and their corresponding requirements for in-coverage, partial coverage, and out-of-coverage NR positioning use-cases were identified as part of a 3GPP RAN-level study during Release 17 that were captured in TR 38.845 [2]. Additionally, requirements defined in TS 22.261 [3] for "Ranging based services” and in TS 22.104 [4] for IIoT use cases in out-of-coverage scenarios were taken into consideration. These initial target requirements were refined further to develop RAN-level target requirements as part of the study item (SI) on expanded and improved NR positioning during Release 18 and captured in TR 38.859 [5]. Following from the studies reported in [5], as part of the current Release 18 WI, RAN WGs introduced support of SL positioning and ranging features with various positioning methods for in-coverage, partial coverage, and out-of-coverage NR positioning use-cases.

The ***improvements*** to high accuracy positioning in NR systems was three-fold and considered: (1) positioning integrity improvements for RAT-dependent positioning methods, (2) positioning accuracy improvements by introducing NR carrier phase measurements and reporting and by leveraging use of larger bandwidths within the NR spectrum based on PRS (Positioning Reference Signal) and SRS (Sounding Reference Signal) bandwidth aggregation for intra-band contiguous carriers, and (3) power efficiency of NR positioning via support of LPHAP (Low Power High Accuracy Positioning) use-cases and high accuracy positioning for RedCap (Reduced Capability) NR UEs.

### 2 Description

#### 2.1 Sidelink Positioning

A new SL reference signal, SL PRS, has been introduced to support SL positioning and ranging for in-coverage, partial coverage, and out-of-coverage scenarios. Transmission of SL PRS via unicast, broadcast, and groupcast modes are supported. Protocol and procedures for SL positioning between UEs and LMF, involving SL Target UE, SL Anchor UE(s), and Location Server (SL Server UE or LMF) are introduced as part of SLPP (SL Positioning Protocol) and specified in TS 38.355 [6]. A SL Target UE is a UE whose distance, direction and/or position is measured with the support from one or multiple SL Anchor UEs using Sidelink in the Ranging based service and Sidelink positioning. A SL Anchor UE is a UE that supports positioning of a target UE, e.g., by transmitting and/or receiving reference signals for positioning, providing positioning-related information, etc. over the SL interface. A Location Server is an entity or UE providing location and/or ranging services to one or more target UE(s), including facilitating transfer of assistance information and coordination with one or more anchor UE(s).

Different SL positioning methods have been introduced to support SL positioning and ranging. These include: (i) SL-RTT (Round Trip Time) that utilize SL Rx-Tx time difference measurements between a target and anchor UE, (ii) SL-AoA (Angle of Arrival), (iii) SL-TDOA (Time Difference of Arrival) method that utilizes SL RSTD (Reference Signal Time Difference) measurements corresponding to SL PRSs received at a target UE from multiple anchor UEs, and (iv) SL-TOA (Time Of Arrival) method that utilizes SL RTOA (Relative Time of Arrival) measurements corresponding to reception of SL PRS transmitted by a target UE at multiple anchor UEs. In addition, SL PRS-RSRP (Reference Signal Received Power) and SL PRS-RSRPP (Reference Signal Received Power per Path) have been introduced.

SL PRS is designed based on DL PRS, utilizing a comb-based mapping to frequency resources and pseudorandom sequence generation. Different comb-sizes and numbers of symbols of SL PRS are supported by the specifications, depending on whether the SL PRS are transmitted in a dedicated or a shared SL PRS resource pool. A dedicated SL PRS resource pool is a SL resource pool which can be used for transmission of one or more SL PRS and associated PSCCH (Physical Sidelink Control Channel) without transmission of PSSCH (Physical Sidelink Shared Channel), while a shared SL PRS resource pool is a SL PRS resource pool which can be used for transmission of both SL PRS and PSSCH. Within a SL carrier, a UE may be configured with one or more dedicated or one or more shared SL PRS resource pools. Both fully staggered SL PRS patterns, where the comb size equals the number of symbols of SL PRS, and partially staggered SL PRS patterns, where the comb size is larger than the number of symbols of SL PRS, are supported.

In a dedicated SL PRS resource pool, SL PRS and its associated PSCCH are multiplexed in time domain while multiple SL PRS resources may be multiplexed via comb-based or TDM (Time Division Multiplexing)-based multiplexing. For a given SL slot, a one-to-one mapping is defined between a SL PRS resource and its associated PSCCH. In contrast, in a shared SL PRS resource pool, a single SL PRS resource can be multiplexed with associated PSCCH, PSSCH, and their associated DMRS (Demodulation Reference Signals) within a single sub-channel. As for the case of SL communication, multiple SL PRS with their associated PSCCH and PSSCH may be multiplexed in frequency at the granularity of sub-channels.

Specifications for transmit power control for SL PRS transmissions follow approaches defined for SL communication, with OLPC (open loop power control) defined for SL PRS transmissions in dedicated SL PRS resource pool based on one or both of SL and DL pathloss measurements with SL PRS as a reference for SL pathloss measurements. For SL PRS transmission in shared SL PRS resource pool, the same transmit power level as determined for PSSCH transmission is used.

In terms of resource allocation for SL PRS, similar to SL communication, two resource allocation modes are supported: (i) network-centric resource allocation, whereby a UE transmits SL PRS using resources as indicated dynamically by the serving gNodeB (gNB) or via SL configured grants types 1 or 2 by the serving gNB, and (ii) UE-autonomous SL PRS resource selection. For dynamic resource allocation for SL PRS, a new DCI (Downlink Control Information) format 3\_2 has been introduced. For UE-autonomous SL PRS resource selection, both random resource selection and sensing-based resource selection methods have been defined. While, for shared SL PRS resource pools, congestion control and IUC (inter-UE coordination) methods are reused from SL communication, for dedicated SL PRS resource pools, separate congestion control methods, that are based on those for SL communication, are defined.

For indication of SL PRS resource allocation, a new single stage SCI (Sidelink Control Information) format 1-B is introduced for dedicated SL PRS resource pool, while a new second stage SCI format 2-D is introduced for shared SL PRS resource pool. No second stage SCI is included in a slot of a dedicated SL PRS resource pool.

SLPP is used point-to-point between Endpoints, e.g. Location Server (SL Server UE or LMF) and SL Target UE in order to obtain absolute position, relative position, or ranging information of SL Target UE using sidelink measurements obtained by one or more reference sources. Each SLPP transaction involves the exchange of one or more SLPP messages between Endpoint A and Endpoint B. The general format of an SLPP message consists of a set of common fields followed by a body. The body (which may be empty) contains information specific to a particular message type. Each message type contains information specific to one or more positioning methods and/or information common to all positioning methods. The following message types are defined:

- Request Capabilities;

- Provide Capabilities;

- Request Assistance Data;

- Provide Assistance Data;

- Request Location Information;

- Provide Location Information;

- Abort;

- Error.

#### 2.2 Positioning integrity for RAT-dependent positioning methods

Positioning integrity is a measure of the reliability in the accuracy of the position-related data and the ability to provide timely warnings based on assistance data provided by the network. During Release 17, specification support for GNSS integrity was introduced. This is being extended in Release 18 to RAT-dependent positioning methods to address relevant integrity aspects of mission critical use-cases that rely on positioning estimates and corresponding uncertainty estimates.

For integrity operation, Integrity Principle of Operation in AGNSS in Rel-17 is reused for RAT-dependent positioning methods in Release 18.

UE-based and LMF-based integrity of RAT-dependent positioning methods including Multi-RTT, DL-AoD, DL-TDOA, UL-TDOA, and UL-AoA are supported via error modeling parameters. On the error source for RAT-dependent positioning methods, there are different error sources such as location errors, timing errors which are estimated and provided in the corresponding assistance data. Only those TRPs for which the integrity assistance data are provided are monitored by the network and can be used for integrity related applications. The mapping between the integrity fields and the assistance data are specified per positioning method.

For UE-based integrity of DL-AoD positioning method, TRP (Transmission Reception Point) location, boresight direction of DL PRS resource and beam information of DL PRS are the error sources. Therefore, the mean and standard deviation of TRP/ARP (Antenna Reference Point) location error, mean and standard deviation of Azimuth/Elevation error of DL PRS resource boresight direction, and mean and standard deviation of beam power error per direction are provided as integrity bounds to UE.

For UE-based integrity of DL-TDOA positioning method, TRP location and inter-TRP synchronization are the error sources. Therefore, the mean and standard deviation of TRP/ARP location error and mean and standard deviation of RTD (Round Trip Delay) error are provided as integrity bounds to UE. All error sources share the same residual risks in each positioning method.

For LMF-based integrity, there is no protocol impact for the relevant positioning methods.

#### 2.3 NR Carrier Phase Positioning

Inspired by the support of GNSS carrier phase positioning that is primarily limited to outdoor applications, NR CPP (Carrier Phase Positioning) has been introduced to enable support of cm-level positioning accuracy that can be utilized in both outdoor and indoor applications. NR CPP is supported via introduction of new carrier phase (CP) measurements that may be reported along with existing positioning measurements, viz., DL RSTD or UE Rx-Tx time difference measurements for DL positioning methods and UL RTOA or gNB Rx-Tx time difference measurements for UL positioning methods.

For DL, two types of CP measurements are defined: (i) DL RSCP (Reference Signal Carrier Phase) measurements that may be reported along with UE Rx-Tx time difference measurements; and (ii) DL RSCPD (Reference Signal Carrier Phase Difference) measurements that may be reported along with DL RSTD measurements. Further, DL CP measurements may be reported by a UE in RRC\_CONNECTED state using measurement gaps for the measurements, or in RRC\_INACTIVE or RRC\_IDLE states. The reported carrier phase is associated with the centre frequency of the DL PFL (Positioning Frequency Layer) to which the DL PRS is mapped, with DL RSCP being defined as the phase of the channel response at the first path delay derived from the REs (resource elements) that carry the DL PRS configured for the measurement.

For UL, UL RSCP measurements are introduced that may be reported by an NG-RAN node (e.g., gNB) along with UL RTOA or gNB Rx-Tx time difference measurements. The reported carrier phase is associated with the centre frequency of the UL SRS for positioning resource, with UL RSCP being defined as the phase of the channel response at the first path delay derived from the REs (resource elements) that carry the UL SRS for positioning configured for the measurement. For UE-based CPP, the LMF can forward, either one time (aperiodic) or periodically, the carrier phase measurements together with the legacy measurement associated with the carrier phase measurement to UE.

Release 17 LOS/NLOS (Line of Sight/Non-Line of Sight) indication for UE RSTD/Rx-Tx time difference measurements applies for the RSCP/RSCPD measurement(s) in the same report. For both DL and UL, reporting of phase quality indication for the RSCP/RSCPD measurements have been introduced.

The accuracy and efficacy of carrier phase measurements are impacted by multiple factors, especially the timing and frequency errors impacting initial phases at both the Tx (transmitter) and Rx (receiver). These errors must be removed to achieve high accuracy CPP. PRUs (Positioning Reference Units) with known location coordinates have been introduced for supporting double-differential (DD) CPP to eliminate these errors. For DL DD-CPP, it is essential that the DL measurements are made by a target UE and a PRU simultaneously or very close in time. Similarly, for UL DD-CPP, it is critical that I SRS for positioning are transmitted from a target UE and a PRU and measured by the gNB(s) simultaneously or very close in time. Accordingly, Release 18 has introduced signalling support to enable the following:

1. Simultaneous measurements of DL PRS at a target UE and a PRU within indicated time window(s).
2. Configuration of SRS transmissions from a target UE and a PRU within indicated time window(s).
3. Requests to the serving gNB and neighboring gNBs of a UE to measure the UL SRS for positioning resources from the UE within indicated time window(s).

It should be noted that the above features for enabling simultaneous DL/UL measurements are applicable for UE in RRC\_CONNECTED, RRC\_INACTIVE, and RRC\_IDLE states, and are not restricted to NR CPP but can be used for other NR DL/UL positioning methods as well.

#### 2.4 Bandwidth Aggregation for DL PRS and SRS for positioning

To enable high accuracy positioning, bandwidth aggregation for DL PRS and SRS for positioning have been introduced whereby DL PRS and SRS for positioning, respectively, are aggregated across intra-band contiguous carriers for single Tx/Rx architectures at gNB and UE. Further detailed conditions for aggregating DL PRS resources and SRS for positioning have been specified. Up to two or three DL PFLs and up to two or three UL carriers can be aggregated. Further, up to two DL PFL combinations (e.g., PFL1 aggregated with PFL2 and PFL3 aggregated with PFL4) can be configured where different combinations are expected to be measured at different time instances, i.e., multiplexed in time domain.

For DL PRS bandwidth aggregation across DL PFLs, the DL PRS to be aggregated are linked on a per-TRP- and per-DL PRS resource set-basis. For SRS for positioning bandwidth aggregation across UL carriers, the UL carriers to be aggregated are linked on a per SRS for positioning resource set-basis. Further, SRS for positioning bandwidth aggregation may be supported independent of the UE’s support of UL CA (Carrier Aggregation) for communication. Accordingly, SRS resource configured within a CC (Component Carrier) without PUSCH/PUCCH can be linked for bandwidth aggregation with an SRS resource configured within an UL active BWP of a UL communication CC.

For DL, support of DL PRS measurements across multiple aggregated DL PFLs for a UE in RRC\_CONNECTED, RRC\_INACTIVE, and RRC\_IDLE states are specified. For RRC\_CONNECTED state, measurements for DL PRS bandwidth aggregation are limited to configured measurement gaps. For UL, support of SRS for positioning bandwidth aggregation is supported for a UE in RRC\_CONNECTED and RRC\_INACTIVE states. Periodic, semi-persistent, and aperiodic SRS for positioning configurations are supported for SRS bandwidth aggregation. For semi-persistent SRS for positioning with bandwidth aggregation, a single MAC (Medium Access Control) CE (Control Element) can activate or deactivate one or more of the aggregated carriers. Similarly, for aperiodic SRS for positioning with bandwidth aggregation, in addition to triggering based on separate DCIs for the respective carriers, a single DCI (e.g., DCI format 0\_3 or 1\_3 for multi-cell PDSCH/PUSCH scheduling or Rel-17 single DCI scheduling positioning SRS resource sets across the linked carriers) can trigger the aperiodic SRS transmission across the linked carriers.

The aggregated measurements may be used for different timing-based positioning measurements, including DL RSTD, UE Rx-Tx time difference, UL RTOA, and gNB Rx-Tx time difference measurements. Additionally, RSRP and RSRPP measurements in DL and UL may be reported where the measurements are based on aggregated DL PRS or aggregated SRS for positioning resources, respectively.

LMF (Location Management Function) can request a UE or NG-RAN node to report aggregated measurements based on bandwidth aggregation across multiple configured DL PFLs or carriers, respectively. When configured for DL PRS bandwidth aggregation, TRP(s) and/or PRS resource set(s) that include PRS aggregation have higher priority than TRP(s) and/or PRS resource set(s) that do not include PRS aggregation. A UE or NG-RAN node may also indicate in a measurement report as to whether and which measurements are based on bandwidth aggregation. To enable reporting of timing measurements with finer timing resolution, the reporting granularity factor for both DL and UL positioning have been enhanced to include the new values of *k = {-1, -2, -3, -4, -5, -6}*. Further, use of the new reporting granularity factor values is not limited to the configuration of bandwidth aggregation feature.

#### 2.5 Low Power High Accuracy Positioning (LPHAP)

The SA1 requirements for high accuracy and extremely low power consumption with battery lifetimes of up to one or more years have been identified for IIoT (Industrial Internet of Things) use-cases such as massive asset tracking, AGV tracking in industrial factory and person localization in danger zones. A typical scenario of interest is use-case #6 as defined TS 22.104, which corresponds to tracking of workpiece (in- and outdoor) in assembly area and warehouse with a target accuracy of <1m, a positioning interval of 15-30 seconds, and a battery lifetime of 6-12 months.

To support LPHAP, multiple enhancements have been introduced in Release 18, including: (i) enhancement of SRS for positioning configurations in RRC\_INACTIVE state for UL and UL+DL positioning based on SRS for positioning validity area to avoid frequent reconfiguration of SRS for positioning upon serving cell changes; (ii) introduction of (e)DRX cycles longer than 10.24 seconds in RRC\_INACTIVE state; (iii) alignment of (e)DRX cycles in RRC\_INACTIVE state and DL PRS configurations, and (iv) support of measurements on DL PRS resources in RRC\_IDLE state with reporting of the corresponding measurements when in RRC\_CONNECTED state.

An SRS for positioning validity area consists of cells, which are configured in the same carrier, with common values of BWP (Bandwidth Part) parameters, viz., *locationAndBandwidth, subcarrierSpacing,* and *cyclicPrefix*, and in which the SRS for positioning configuration in RRC\_INACTIVE state is valid*.* Further, various parameters for the SRS for positioning configuration (via *srs-PosConfig*) and SRS for positioning resource configuration (via *SRS-PosResource*) are commonly configured across these cells. Furthermore, methods for determination of UL timing and TA (timing advance) values, spatial relation for SRS for positioning, and pathloss RS (reference signal) for transmit power control within an SRS for positioning validity area have been specified.

When configured with an SRS for positioning configuration along with SRS for positioning validity area, if a UE reselects to another cell within the SRS positioning validity area during SRS transmission, the UE continues the SRS transmission, subject to validation for SRS transmission. When the UE reselects out of the SRS for positioning Validity Area during SRS transmission, the UE may send an "RRC Resume Request" message to the network for SRS configuration request.

The SRS for positioning configuration in RRC\_INACTIVE state may be preconfigured in the target device. The target device may send an "RRC Resume Request" message to the network when a configured periodic or triggered location event has been detected to request activation of the pre-configured SRS for positioning. For preconfigured multiple SRS configurations, the UE is configured with only one SRS for positioning configuration for each validity area.

The eDRX cycles longer than 10.24 seconds in RRC\_INACTIVE state which are introduced as part of eRedCap WI is reused for LPHAP. Legacy UE-initiated on-demand PRS request procedure can also be used to align DL PRS to fixed (e)DRX in order to reduce the power consumption of UE for LPHAP.

For LPHAP, positioning measurements may be performed when a UE is in RRC\_IDLE state and reported when in RRC\_CONNECTED state to reduce the power consumption. A UE may utilize the positioning assistance data received via broadcast or the positioning assistance data received while in RRC\_CONNECTED state when performing positioning measurements in RRC\_IDLE state.

#### 2.6 Positioning for RedCap UEs

RedCap (Reduced Capability) NR UEs, with reduced maximum UE bandwidth of 20 MHz and 100 MHz in FR1 and FR2 respectively and reduced numbers of Rx antennas have been introduced in Release 17. As a consequence of reducing the maximum UE bandwidth, the achievable positioning accuracy was observed to be degraded compared to regular NR UEs. Such observations were documented in [5] and motivated the consideration of enhancements in Release 18 involving reception of DL PRS with Rx (receiver) frequency hopping and transmission of SRS for positioning with Tx (transmitter) frequency hopping to enable measurements spanning a wider bandwidth than maximum UE bandwidth for RedCap or Release 18 eRedCap UEs.

Frequency hopping-based reception and transmission are defined within a DL PRS resource and within an SRS for positioning resource, with switching times between frequency hops that are shorter than typical BWP switching times specified in Release 15. For DL Rx frequency hopping, a single instance of a configured measurement gap is used for receiving all the hops for DL PRS with Rx frequency hopping. For UL Tx frequency hopping, the frequency hopping pattern can be configured with overlapping or non-overlapping hops and following a wrapped staircase pattern. Further, the SRS for positioning resource is be configured outside of the active UL BWP configuration of the UE. In time domain, a frequency hopping pattern for SRS for positioning with Tx frequency hopping may be contained within a single slot or may span multiple slots and can be configured for periodic, semi-persistent, and aperiodic SRS for positioning.

An LMF may include an explicit request via the location request signaling for DL PRS Rx hopping measurements and reporting. The location information request can also optionally include the total bandwidth of all hops. For reporting of measurements, for DL Rx frequency hopping or UL Tx frequency hopping, a UE or NG-RAN node may report a single measurement based on receiving multiple hops of the DL PRS or UL SRS for positioning or a measurement associated with one received hop, with optional reporting of whether the measurement is based on a single-hop or multiple hops.

DL Rx frequency hopping for DL PRS reception is supported for a UE in RRC\_CONNECTED state within configured measurement gaps, or in RRC\_INACTIVE, or RRC\_IDLE states. UL Tx frequency hopping for SRS for positioning transmission is supported for a UE in RRC\_CONNECTED state or in RRC\_INACTIVE state. New collision rules between SRS for positioning with frequency hopping and other UL and DL signals/channels have been introduced. In addition to the new collision rules, for UL Tx frequency hopping-based transmissions, a periodically occurring UTW (Uplink Time Window) may be optionally configured to a UE within which the UE is not expected to transmit other signals/channels and is only expected to transmit FH SRS for positioning. When UTW is configured, collision rules are applied outside the UTW.

### 3 References

1. RP-233382, “Revised WID on Expanded and Improved NR Positioning,” Intel Corporation, CATT, Ericsson, December 2023.
2. 3GPP TR 38.845: "Study on scenarios and requirements of in-coverage, partial coverage, and out-of-coverage NR positioning use cases".
3. 3GPP TS 22.261, "Service requirements for the 5G system".
4. 3GPP TS 22.104: "Service requirements for cyber-physical control applications in vertical domains".
5. 3GPP TR 38.859, “Study on expanded and improved NR positioning (Release 18)”.
6. 3GPP TS 38.355, “NR; Sidelink Positioning Protocol (SLPP); Protocol Specification”.