White Paper

Anritsu Advancing beyond

Introduction to 5G Positioning Technologies

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Introduction

5G is expanding into new industry segments, but also expanding into new technology areas. One of the key phrases for the introduction of 5G has been the new use cases that support industrial verticals, where 5G can be used for different industries. Whereas 2G/3G/4G were mostly focussed on consumer services such as voice, messaging and mobile browsing.

Industry Segments for 5G

At the start of 5G, it was shown as a concept of a triangle with three key areas, as shown below.

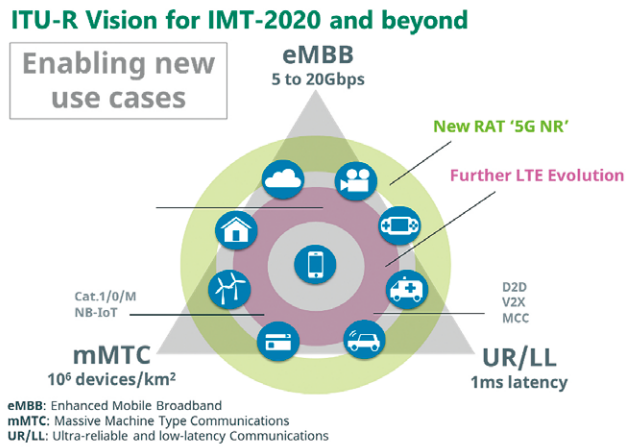


Figure 1: 5G Usage Scenarios

- eMBB is the existing consumer driven services, which include position/location services to support mapping and navigation services (e.g. Google Maps).
- mMTC is the expansion of the IoT market to support scaling up to many times more devices, with affordable devices and sufficient capability/capacity in the network to handle so many new IoT devices.
- UR/LLC is the move into new industrial segments where new performance targets on reliability and latency are required to give the required level of performance.

New Technologies Evolving with 5G Deployment

Three of the key new technologies which are added to the 5G network system, to enable the new industry segments discussed above, are:

Precise Positioning
- Relevant to Smartphone, IoT module (item tracking), automotive (HD maps).

Non Terrestrial Networks (NTN)
- Relevant to RAN/BTS, Smartphone, FWA/CPE.

MEC and Virtualisation
- Applications test for Smartphone, Smart Factory, Automotive.

Key Concept of 3GPP Precise Positioning

The key concept is to utilise 3GPP signalling in the 5G network to enhance the performance of position calculation. This involves using both the existing signals in the 5G network, and introducing some specific new signals which are to directly support the enhanced positioning capability.

The 5G positioning capabilities being introduced as 3GPP Precise Positioning features can supplement to GNSS, to enhance accuracy and/or improve the measurement time. In addition, it can provide position information when GNSS is not available (e.g. indoor environment, such as inside a factory).

Applications of 3GPP Precise Positioning

The first focus application area is for 5G Connected devices that require high accuracy position (e.g. autonomous vehicles/robots), or indoor positioning (e.g. factory robot, smartphone user). For these devices, the availability of GNSS positioning signals from satellite, or the position accuracy available, may not always meet the requirements of the application. For the indoor positioning example, we can also expect to deploy the Precise Positioning technology in 'Local 5G' networks used for industrial applications. Within 3GPP specifications this type of 'Private 5G network' is described as a Stand-Alone Non Public Network (SNPN).

Four of the leading target markets are:

1. Smartphone: Indoor positioning services (no satellite line-of-sight).
2. Autonomous Vehicles, high accuracy positioning. (5GAA has dedicated work item to this technology).
3. IoT, 'industrial asset tracking' of items when no satellite signal is available (indoor, inside packaging, etc).
4. Warehouse/manufacturing, automation of robots with high accuracy indoor positioning.

Technology Landscape for Precise Positioning

As we can see in the diagram below, positioning technologies can be mapped out according to the positioning accuracy requirements of different use cases.

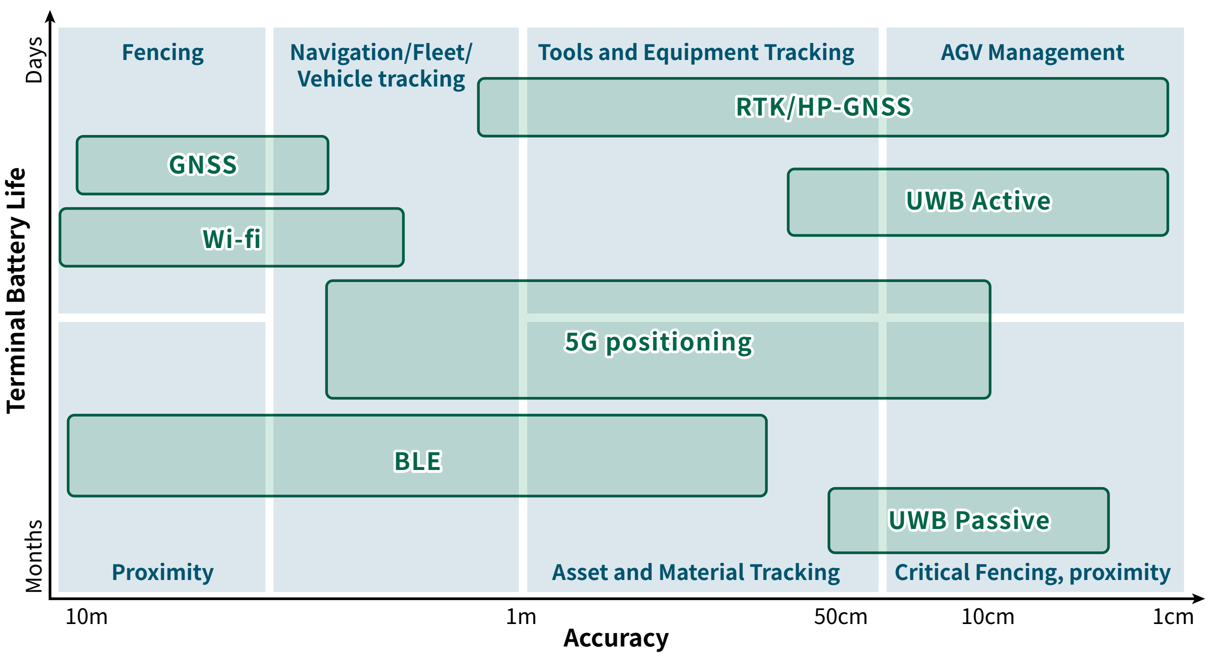


Figure 2: Real Time Location Service Technology Comparison

For positioning in the 5 m to 10 m accuracy, then normal commercial grade GNSS can be used and also Wi-Fi (proximity to a known hotspot location) are possible. For longer battery life, then proximity to a Bluetooth® beacon can also be used.

For very high accuracy positioning, in the 1 cm to 50 cm range then UWB is often used, either as passive method (for long battery life) or as an active method (with greater range accuracy to support very short ranges). In addition, RTK (Real Time Kinetic) and HP-GNSS (High Precision GNSS) can provide very high accuracy by using supplementary position signals from a local known precise location, which is used to supplement the basic GNSS signal and provide high position resolution.

RTK, also known as 'Dead Reckoning' uses motion sensors to estimate the movement of device and then update relative position. This technique is a combination of GNSS to establish a reference position, and then motion sensors to update the position information when reliable GNSS signal/data is not available.

Bluetooth Low Energy (BLE) and Bluetooth v5.x (with AoA and AoD) has also introduced positioning features that enable long battery life and position accuracy in the range 1 m to 10 m. This is aimed at providing position information when a Bluetooth device is within the range of a suitable Bluetooth beacon, to enhance the position location within the coverage of the beacon. The measurement of Angle of Arrival (AoA) and/or Angle of Departure (AoD) enable geometric positioning within the coverage area of the beacon to be performed.

5G NR positioning is a set of 3GPP Precise Positioning features being introduced to enable the 3GPP network to enhance or substitute the other positioning techniques. 5G positioning has 'mid range' performance, to cover a wide range of use cases. Previous functions in 3GPP (e.g LTE/EPC) have only supported GNSS assistance functions, to help the Time To First Fix or position accuracy possible using GNSS systems. With the possibility to operate as a 'stand-alone' positioning capability, 5G positioning will inherit many advantages of 5G infrastructure that could potentially enhance its accuracy, including:

- Large cell site density to enable better positioning accuracy through many diversified anchor points available for generating and processing positioning.
- The deployment of massive Multiple Input, Multiple Output (MIMO) and beamforming, which could enhance the direction accuracy for algorithms like Angle of Arrival (AoA) and Direction of Arrival (DoA).
- The use of high-frequency channels by 5G networks, which could contribute to better accuracy through reduced channel sparsity due to better array gains.
- Large bandwidth provided by a 5G network could offer better multipath resolution and, therefore, high accuracy for measuring distances, which again could contribute to improving the accuracy of positioning measurements.
- Single infrastructure handling positioning and telecommunication functions, which will not only help in lowering the overall infrastructure cost, but could open the possibility to a range of new geo-information applications.

These features will enable 5G positioning to follow the overall 5G steps and create new opportunities in industrial asset tracking and commercial automation applications. These two applications are core for creating the Industrial IoT (IIoT) capability that will allow business owners to monitor and locate workers, assets, and tools in real time with a high level of accuracy. Coupled with IIoT software platforms, this can enable businesses to increase automation and enhance the efficiency of their factory processes

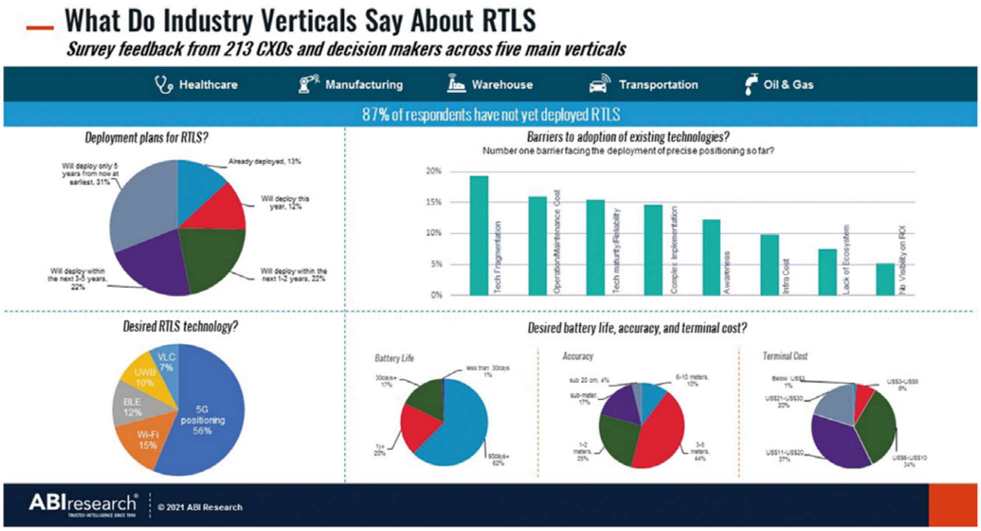
Table 1: 3GPP Summary of Positioning Methods (TS38.305)

Method	UE-based	UE-assisted, LMF-based	NG-RAN node assisted	SUPL*8
A-GNSS	Yes	Yes	No	Yes
OTDOA*1, *2	No	Yes	No	Yes
E-CID*4, *7	No	Yes	Yes	Yes for E-UTRA
Sensor	Yes	Yes	No	No
WLAN	Yes	Yes	No	Yes
Bluetooth	No	Yes	No	No
TBS*5	Yes	Yes	No	Yes (MBS)
DL-TDOA	Yes	Yes	No	Yes
DL-AoD	Yes	Yes	No	Yes
Multi-RTT	No	Yes	Yes	Yes
NR E-CID	No	Yes	Yes	Yes (DL NR E-CID)
UL-TDOA	No	No	Yes	Yes
UL-AoA	No	No	Yes	Yes

*1: This includes TBS positioning based on PRS signals.
*2: In this version of the specification only OTDOA based on LTE signals is supported.
*3: Void
*4: This includes Cell-ID for NR method when UE is served by gNB.
*5: In this version of the specification only for TBS positioning based on MBS signals.
*6: Void
*7: Enhanced Cell ID based on LTE signals.
*8: This shows whether the positioning method is supported by SUPL ULP.

Industry Analysis of 5G Positioning Technology for Real Time Location Services

A 2021 survey from ABI Research shows that just over 50% of companies in 5 related industry verticals (healthcare, manufacturing, warehouse, transportation, oil & gas) plan to deploy Real Time Location Services within next 5 years (total of this year, 1-2 years, and 3-5 years), with current deployment rate at 13%. Technology fragmentation (the need to support multiple technologies within a single solution) and cost of operation & maintenance were shown as the two main barriers to adoption of existing technologies. 5G Positioning was shown to be a preferred solution (56% preferred) as it addresses the key barriers to adoption by providing precise positioning within an existing deployed and managed 5G network.



Source: ABI Research website

Figure 3: Survey Feedback about RTLS

3GPP Positioning Roadmap

3GPP released "5G New Radio" initially in the Release 15 of standards, but this was using a 4G Core Network and operated the 5G radio in 'Non Stand Alone' (NSA) mode. For full 5G capabilities, including the Stand Alone (SA) mode using a new 5G core network, then this has been supported from Release 16 onwards. So the Release 15 NSA version of 5G did not introduce any 5G precise positioning features, only the ability to use a 5G radio connected to a 4G core network.

3GPP Release 16/17/18 Items

Release 16 supports multi-/single-cell and device-based positioning, defining a new positioning reference signal (PRS) used by various 5G positioning techniques such as roundtrip time (RTT), angle of arrival/departure (AoA/AoD), and time difference of arrival (TDOA). Roundtrip time (RTT) based positioning removes the requirement of tight network timing synchronization across nodes (as needed in legacy techniques such as TDOA) and offers additional flexibility in network deployment and maintenance. These techniques are designed to meet initial 5G requirements of 3 and 10 meters for indoor and outdoor use cases, respectively.

In Release 17, precise indoor positioning functionality will bring sub-meter accuracy for industrial IoT use cases. Currently the Release 17 specifications are still being finalised and the actual capabilities and performance have not been fully confirmed.

Release 18 topics include Expanded and improved Positioning, with the following example areas: Sidelink positioning/ranging, Improved accuracy, integrity, and power efficiency, RedCap (Reduced Capability terminals) positioning. Release 18 is only in definition phase, setting objectives and topics, and no further details of capability or performance are yet available.

NR-Sidelink Positioning

From Release 16 of 5G NR there is support of 'sidelink' for direct mode device to device communication, and this can be under network coverage, partial coverage, or no coverage conditions. This enables devices to directly communicate with other neighbouring devices even when there is no network coverage, and allows for very low latency communication as no network latency is present. As part of the enhancement of Sidelink technology in Release 17, then additional features to support position sensing using Positioning Reference Signals (PRS) are being developed. This will enable the Sidelink mode to support TDOA and Power level methods to measure distance and direction to another device. Sidelink positioning is envisaged to be supporting the measurement of relative location between two devices, and the Sidelink position information would normally be augmented with other relative and absolute position information (e.g. GNSS, 5G cell based positioning) to provide an enhanced absolute position estimate.

Future Evolution of 3GPP Positioning, Outline of Release 17 Topics

The work item 'Enhancement to the 5GC location services', included in Release 17, aims to provide support for very low latency and very high accuracy positioning, including horizontal and vertical positioning service levels, and 5G positioning service area.

'Enhancement to the 5GC location services', included in Release 17, will provide support for very low latency and very high accuracy positioning. NR has supported positioning since Rel-15 through the use of LTE positioning (for non-standalone deployments) and radio-access technology (RAT) independent positioning (Bluetooth, wireless LAN, pressure sensors). Rel-16 introduced time-based positioning methods for NR standalone deployments (multi-round-trip time (RTT), Downlink and Uplink Time Difference of Arrival), as well as an angle-of-arrival and angle-of-departure-based positioning measurements, which can be used in combination with timing-based solutions to achieve higher accuracy.

In Rel-17, NR positioning is further improved for specific use cases such as factory automation by targeting 20 cm to 30 cm location accuracy for certain deployments. Rel-17 also introduces further enhancements to latency reduction to enable positioning in time-critical use cases such as remote-control applications. As well as high-positioning accuracy, industrial Internet of Things (IIoT) and automotive use cases also demand integrity protection (security) of the location information. From a higher layer point of view, Rel-17 introduces key performance indicators to indicate the reliability/integrity of the measurement report limited to the global navigation satellite system (GNSS) positioning procedure.

Some of the SA1 Rel-16 defined requirements have not been studied during Rel-16, e.g. very low latency and very high accuracy for IIoT and other applications, positioning service area and positioning service level. To enhance 5G System location service to satisfy the above requirements, further work to enhance 5G Location Services was made in Release 17. Within the 3GPP Technical Specification Group Service and System Aspects (TSG SA), the main objective of 3GPP TSG SA WG2 (SA2) is to develop the overall 3GPP system architecture and services including User Equipment, Access Network, Core Network, and IP Multimedia Subsystem. The objective of the Release 17 work item was to further enhance the 5GC location services architecture and corresponding network functions and procedures to meet the full set of requirements defined in SA1. This includes support of service requirements for IIoT and other use cases and enable MCX UE to use the 5G positioning services to determine its position. Note that solutions in Rel-17 should avoid or minimize impact to Rel-16 5GC LCS architecture, interfaces, network functions (NF), and NF services in 5GC.

Release 18 Topics

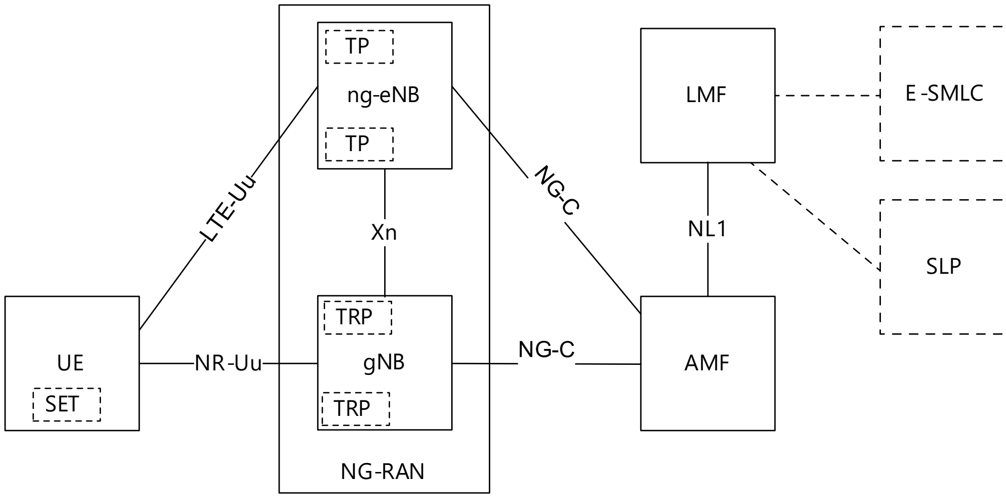
At the time of writing, 3GPP is studying and defining topics for expanded and improved Positioning, with the following example areas:

- Sidelink positioning/ranging
- Improved accuracy, integrity, and power efficiency
- RedCap positioning

It is seen from the automotive industry that the Sidelink positioning feature is of high interest, to provide positioning capability in scenarios where GNSS coverage is not available (e.g. tunnel, urban canyon, underground parking).

RedCap is the 3GPP feature for Reduced Capability terminals, which is introducing lower cost and lower specification devices to address certain market needs such as IoT. Currently the use case for RedCap positioning is not defined, given the focus to reduced cost of implementation. But it is thought that an enhanced positioning capability that can be provided by the 5G network can be of value for IoT applications. The cost/complexity of implementation, and performance capability under RedCap restricted mode, should be evaluated as part of these studies.

Network Architecture for 5G Positioning Services



Source: 3GPP TS 38.305

Figure 4: 5G Network Architecture

The architecture shown above is the 5G network elements related to positioning services. This is based on the 5G Core network concept (5GC) where all functions of the core network are described as logical functions (i.e. input and output) and not described in terms of physical implementation. This is aimed to enable the 5GC to be virtualised and implemented into cloud networks, and to be independent of underlying technology implementation. The 5GC control plane connection (NG-C) provides the control plane connection from RAN to the AMF (Access and Mobility Function) to enable control of the UE access and mobility functions. From the AMF, a new interface (NL1) provides a connection to the new function for Location Management Function (LMF) which is responsible for managing all location services in the 5GC. So all location information is sent to/ from the UE to the LMF, using the 5GC control plane messages and routing through the AMF on the NL1 interface.

The LMF is responsible to select which positioning methods to use for each UE, based on UE capabilities and RAN capabilities and any other position information that is available for the specific UE. The LMF is then responsible for combining the different position information elements to make a 'best guess' calculation of the position of the UE, when a RAN or LMF assisted positioning is used. The LMF is also responsible for providing the suitable Reference Signal configuration information to multiple gNB's when there is a triangulation of multiple signals to be used for position estimation.

Overview of 3GPP New Features for 5G Positioning

The 5G positioning methods may be supported in UE-based, UE-assisted/LMF-based, and NG-RAN node assisted versions. There are six fundamental types of RAT dependent (i.e. using the 5G NR Radio Access Technology) positioning function available in 3GPP, each using different aspects of the UE and Network capabilities and different types of radio measurements in the UE or gNb. These six types are listed below:

- DL TDOA – Downlink Time Difference of Arrival
- DL AoD – Downlink Angle of Departure
- UL TDOA – Uplink Time Difference of Arrival
- UL AoA – Uplink Angle of Arrival (Azimuth and Zenith)
- Multi-RTT – Multi Round Trip Time
- NR E-CID – NR Enhanced Cell ID

UE specific features. (DL-TDOA, DL-AoD; UE-based)

UE related features. (DL-TDOA, DL-AoD, Multi-RTT, NR E-CID, UL-TDOA; UE-based and UE-assisted, LMF-based)

Method	UE-based	UE-assisted, LMF-based	NG-RAN node assisted
DL-TDOA	Yes	Yes	No
DL-AoD	Yes	Yes	No
Multi-RTT	No	Yes	Yes
NR E-CID	No	Yes	Yes
UL-TDOA	No	No	Yes
UL-AoA	No	No	Yes

Figure 5: Supported Versions of UE Positioning Methods (Defined in TS38.305)

Physical Layer Signals and Measurements:
In order to support the six RAT-dependent positioning solutions, the following new reference signals and new physical layer measurements are specified. These reference signals and measurements are used to then create positioning reports which are sent between the UE and the Network

Reference signals (defined in TS 38.211)

- DL Positioning Reference Signals (DL PRS)
- UL Sounding Reference Signals (SRS) for positioning

Physical layer measurements (defined in TS 38.215)

UE measurements

- DL PRS-RSRP (downlink positioning reference signals - reference signal receiver power): Applied for DL AoD, DL TDOA, Multi-RTT
- DL RSTD (downlink reference signal time difference): Applied for DL TDOA
- UE Rx – Tx time difference: Applied for Multi-RTT

NG-RAN (gNB) measurements

- UL RTOA (uplink relative time of arrival): Applied for UL TDOA
- UL SRS reference signal received power (UL SRS-RSRP): Applied for UL TDOA, UL AoA, Multi-RTT
- gNB Rx – Tx time difference: Applied for Multi-RTT:
- UL AoA (uplink angle of arrival): Applied for UL AoA and E-CID

In addition, the existing RRM measurements are re-used for NR E-CID support: CSI-RSRP, CSI-RSRQ, SS-RSRP, SS-RSRQ. These are used to measure signal power and quality received in the UE, and then the reported results are used by the network to estimate the distance from gNB to the UE.

UE-based Measurement Reports for Positioning:

- Downlink reference signal reference power (DL RSRP) per beam/gNB
- Downlink reference signal time difference (DL RSTD)
- UE RX-TX time difference

gNB-based Measurement Reports for Positioning:

- Uplink angle-of-arrival (UL-AoA)
- Uplink reference-signal receive power (UL-RSRP)
- UL relative time of arrival (UL-RTOA)
- gNB RX-TX time difference

NR Positioning Schemes in Release 16

• Downlink Time Difference of Arrival (DL-TDOA)

A new reference signal known as the positioning reference signal (PRS) is introduced in Release 16 for the UE to perform downlink reference signal time difference (DL RSTD) measurements for each base station's PRSs. These measurements are made by the UE on the downlink signals from the base station and then reported on the Uplink to the location server.

In the DL-TDOA positioning method, the UE position is estimated based on DL RSTD (and optionally DL-PRS-RSRP) measurements taken at the UE of downlink radio signals from multiple NR TRPs, along with knowledge of the geographical coordinates of the TRPs and their relative downlink timing.

The LMF is able to provide assistance information to the UE to indicate the cells and measurements to take, and then receives back from the UE specific information on the observed time differences of arrival and time of the measurement. The UE may also have some additional location information (e.g. GNSS based) that may also be shared with the LMF.

The assistance data that may be transferred from LMF to the UE is listed in table 2.

Table 2: Assistance Data that may be Transferred from LMF to the UE

Information	UE-assisted	UE-based
Physical cell IDs (PCIs), global cell IDs (GCIs), ARFCN, and PRS IDs of candidate NR TRPs for measurement	Yes	Yes
Timing relative to the serving (reference) TRP of candidate NR TRPs	Yes	Yes
DL-PRS configuration of candidate NR TRPs	Yes	Yes
SSB information of the TRPs (the time/frequency occupancy of SSBs)	Yes	Yes
Spatial direction information (e.g. azimuth, elevation etc.) of the DL-PRS Resources of the TRPs served by the gNB	No	Yes
Geographical coordinates of the TRPs served by the gNB (include a transmission reference location for each DL-PRS Resource ID, reference location for the transmitting antenna of the reference TRP, relative locations for transmitting antennas of other TRPs)	No	Yes
Fine Timing relative to the serving (reference) TRP of candidate NR TRPs	No	Yes
PRS-only TP indication	Yes	Yes

The measurement results that may be transferred from UE to the LMF are listed in table 3.

Table 3: Measurement Results that may be Transferred from UE to the LMF

Information	UE-assisted	UE-based
Latitude/Longitude/Altitude, together with uncertainty shape	No	Yes
PCI, GCI, ARFCN, PRS resource ID, PRS resource set ID and PRS ID for each measurement	Yes	No
DL RSTD measurement	Yes	No
DL-PRS-RSRP measurement	Yes	No
Time stamp of the measurements	Yes	No
Time stamp of location estimate	No	Yes
Quality for each measurement	Yes	No

The specific positioning techniques used to estimate the UE's location from this information are beyond the scope of the 3GPP specification and are vendor specific.

• Uplink Time Difference of Arrival (UL-TDOA)

The Release-16 sounding reference signal (SRS) is enhanced to allow each base station to measure the uplink relative time of arrival (UL-RTOA) and report the UL-SRS-RSRP measurements to the location server. These measurements are made by the base station on the Uplink signals from the UE and then reported directly to the location server.

In order to obtain uplink measurements, the TRPs need to know the characteristics of the SRS signal transmitted by the UE for the time period required to perform uplink measurement. These characteristics should be static over the periodic transmission of SRS during the uplink measurements. Hence, the LMF will indicate to the serving gNB the need to direct the UE to transmit SRS signals for uplink positioning. It is up to the serving gNB to make the final decision on resources to be assigned and to communicate this SRS configuration information back to the LMF so that LMF can forward the SRS configuration to the TRPs. The gNB may decide (e.g., in case no resources are available) to configure no resources for the UE and report the empty resource configuration to the LMF.

The UL-TDOA requested UL-SRS transmission characteristics information that may be transferred from LMF to gNB is listed in table 4.

Table 4: UL-TDOA Requested UL-SRS Transmission Characteristics Information that may be Transferred from LMF to gNB

Information
Number Of Transmissions/duration for which the UL-SRS is requested
Bandwidth
Resource type (periodic, semi-persistent, aperiodic)
Pathloss reference: - PCI, SSB Index, SSB configuration (time/frequency occupancy of SSBs) - DL-PRS ID, DL-PRS Resource Set ID, DL-PRS Resource ID
Spatial relation info - PCI, SSB Index, SSB configuration (time/frequency occupancy of SSBs) - DL-PRS ID, DL-PRS Resource Set ID, DL-PRS Resource ID - NZP CSI-RS Resource ID - SRS Resource ID - Positioning SRS Resource ID
SSB Information
Periodicity of the SRS for each SRS resource set
Carrier frequency of SRS transmission bandwidth

The UL-TDOA TRP measurement request information that may be transferred from LMF to gNB is listed in table 5.

Table 5: UL-TDOA TRP Measurement Request Information that may be Transferred from LMF to gNB.

Information
TRP ID, cell ID of the TRP to receive UL-SRS
UE-SRS configuration
UL timing information together with timing uncertainty, for reception of SRS by candidate TRPs
Report characteristics for the measurements
Measurement Quantities
Measurement periodicity
Measurement beam information request

The specifics of any UL-TDOA positioning methods or techniques used to estimate the UE's location from these measurements are beyond the scope of the 3GPP specification and are vendor specific.

• Downlink Angle-of-departure (DL-AoD)

The UE measures the downlink positioning reference signal receive power (DL PRS RSRP) per beam/gNB. Measurement reports are generated by the UE and sent on the uplink to the base station. These reports are used to determine the AoD based on UE beam location for each gNB. The location server then uses the AoDs to estimate the UE position, based on the spatial information of the downlink beams and the known gNB co-ordinates.

The LMF is able to provide assistance information to the UE to indicate the cells and measurements to take, and then receives back from the UE specific information on the power levels and time of the measurement. The UE may also have some additional location information (e.g. GNSS based) that may also be shared with the LMF.

The DL-AoD assistance data that may be transferred from LMF to the UE is listed in table 6.

Table 6: DL-AoD Assistance Data that may be Transferred from LMF to the UE

Information	UE-assisted	UE-based
Physical cell IDs (PCIs), global cell IDs (GCIs), ARFCN, and PRS IDs of candidate NR TRPs for measurement	Yes	Yes
Timing relative to the serving (reference) TRP of candidate NR TRPs	Yes	Yes
DL-PRS configuration of candidate NR TRPs	Yes	Yes
SSB information of the TRPs (the time/frequency occupancy of SSBs)	Yes	Yes
Spatial direction information (e.g. azimuth, elevation etc.) of the DL-PRS Resources of the TRPs served by the gNB	No	Yes
Geographical coordinates of the TRPs served by the gNB (include a transmission reference location for each DL-PRS Resource ID, reference location for the transmitting antenna of the reference TRP, relative locations for transmitting antennas of other TRPs)	No	Yes
PRS-only TP indication	Yes	Yes

The DL-AoD measurement results that may be transferred from UE to the LMF are listed in table 7.

Table 7: DL-AoD Measurement Results that may be Transferred from UE to the LMF

Information	UE-assisted	UE-based
Latitude/Longitude/Altitude, together with uncertainty shape	No	Yes
PCI, GCI, ARFCN, PRS resource ID, PRS resource set ID and PRS ID for each measurement	Yes	No
DL-PRS-RSRP measurement	Yes	No
Time stamp of the measurements	Yes	No
Time stamp of location estimate	No	Yes
DL-PRS receive beam index	Yes	No

The specific positioning techniques used to estimate the UE's location from this information are beyond the scope of the 3GPP specifications, and are vendor specific.

• Uplink Angle-of-arrival (UL-AOA)

The gNB measures the angle-of-arrival based on the direction and location of the beam in which the UE is located. The UE position is estimated based on UL-AoA (and optionally UL-SRS-RSRP) of uplink radio signals taken at different TRPs, and gNB measurement reports are sent to the location server LMF.

In order to obtain uplink measurements, the TRPs need to know the characteristics of the SRS signal transmitted by the UE for the time period required to calculate uplink measurement. These characteristics should be static over the periodic transmission of SRS during the uplink measurements. Hence, the LMF will indicate to the serving gNB the need to direct the UE to transmit SRS signals for uplink positioning. It is up to the gNB to make the final decision on resources to be assigned and to communicate this configuration information back to the LMF so that LMF can configure the TRPs. The gNB may decide (e.g., in case no resources are available) to configure no resources for the UE and fail the corresponding NRPPa procedure.

UL-AoA TRP measurement request information that may be transferred from LMF to gNB is listed in table 8.

Table 8: UL-AoA TRP Measurement Request Information that may be Transferred from LMF to gNB

Information
TRP ID, cell ID of the TRP to receive UL-SRS
UE-SRS configuration
UL timing information together with timing uncertainty, for reception of SRS by candidate TRPs
Report characteristics for the measurements
Measurement Quantities
Measurement periodicity
Measurement beam information request

The UL-AoA measurement results that may be transferred from gNBs to the LMF are listed in table 9.

Table 9: UL-AoA Measurement Results that may be Transferred from gNBs to the LMF

Measurement Results
NCGI and TRP ID of the measurement
UL Angle of Arrival (azimuth and elevation)
UL-SRS-RSRP
Time stamp of the measurement
Quality for each measurement
Beam information for each measurement

The specific of any UL-AoA positioning methods or techniques used to estimate the UE's location from these measurements are beyond the scope of the 3GPP specification and are vendor specific.

• Multi-cell Round Trip Time (RTT):

The gNB and UE perform Rx-Tx time difference measurement for the signal of each cell, when there are multiple cells available to serve the UE. The measurement reports from the UE and gNB's are sent to the location server to determine the round trip time of each cell and derive the UE position based on triangulation from the known gNB positions.

In the Multi-RTT positioning method, the UE position is estimated based on measurements performed at both the UE and the TRP's. The measurements performed at the UE and TRPs are UE/gNB Rx-Tx time difference measurements (and optionally DL-PRS-RSRP and UL-SRS-RSRP) of DL-PRS and UL-SRS, which are used by an LMF to determine the RTTs.

Assistance Information, and the subsequent measurement results, can be transferred directly between the LMF and the UE. The LMF will indicate which parameters and cells to measure, and the UE will return the corresponding results. Equally, there is information exchange between the gNB's and the LMF to request information, indicate measurement configuration data, and send the corresponding measurement results. The LMF will then calculate and estimate of the UE location based on the RTT information from both the UE and gNB's, and based on the known gNB locations, to triangulate the Time of Flight to estimate UE location.

The RTT assistance data that may be transferred from LMF to the UE is listed in table 10.

Table 10: RTT Assistance Data that may be Transferred from LMF to the UE

Information
Physical cell IDs (PCIs), global cell IDs (GCIs), and PRS IDs, ARFCNs of candidate NR TRPs for measurement
Timing relative to the serving (reference) TRP of candidate NR TRPs
DL-PRS configuration of candidate NR TRPs
SSB information of the TRPs (the time/frequency occupancy of SSBs)
PRS-only TP indication

The Measurement results that may be transferred from UE to the LMF are listed in table 11.

Table 11: Measurement Results that may be Transferred from UE to the LMF

Information
PCI, GCI, and PRS ID, ARFCN, PRS resource ID, PRS resource set ID for each measurement
DL-PRS-RSRP measurement
UE Rx-Tx time difference measurement
Time stamp of the measurement
Quality for each measurement
TA offset used by UE

• Enhanced Cell ID (E-CID)

This is based on RRM measurements (e.g. DL RSRP) of each gNB at the UE. The measurement reports are sent to the location server. The normal Cell ID measurement procedure is to read the cell ID of the cell where the UE is connected, and to use the coverage area of this cell as the 'location' of the UE. But this has only the position accuracy of the whole cell area. So an enhanced Cell ID procedure measures the received power at the UE to then estimate the distance from gNB location to the UE, and hence determine a radius at which the UE is located. This enhanced cell ID report can be combined with other reports (e.g. triangulation with other measurements on other cells, or angle of arrival/departure information) to improve the position accuracy within the cell.

NR Enhanced Cell ID (NR E-CID) positioning refers to techniques which use UE and/or NR radio resource related measurements to improve the UE location estimate. In the case of uplink NR E-CID inter-RAT E-UTRA measurements reported by UE may also be used. For NR E-CID positioning methods the UE reports only the measurements that it has available rather than being required to take additional measurement actions.

NR E-CID measurements may include:

UE measurements (TS 38.215 [37]):

- SS Reference signal received power (SS-RSRP);
- SS Reference Signal Received Quality (SS-RSRQ);
- CSI Reference signal received power (CSI-RSRP);
- CSI Reference Signal Received Quality (CSI-RSRQ).

gNB measurements (TS 38.215 [37]):

- UL Angle of Arrival (azimuth and elevation).

Various techniques exist to use these measurements to estimate the location of the UE. The specific techniques are beyond the scope of this specification.

The NR E-CID Information that may be transferred from gNB to the LMF is listed in table 12.

Table 12: NR E-CID Information that may be Transferred from gNB to the LMF

Information
UL Angle of Arrival (azimuth and elevation)
Cell Portion ID
NR Measurement Results List: - SS Reference signal received power (SS-RSRP) - SS Reference Signal Received Quality (SS-RSRQ) - CSI Reference signal received power (CSI-RSRP) - CSI Reference Signal Received Quality (CSI-RSRQ) - NR Cell Global Identifier /Physical Cell ID
E-UTRA Measurement Results List: - E-UTRA Physical Cell ID - E-UTRA Reference Signal Received Power (RSRP) - E-UTRA Reference Signal Received Quality (RSRQ)

Industry Case Study: Automotive Segment is Very Active to Use 5G Positioning

The automotive industry is expected to be one of the lead users of 5G Precise Positioning, to enable connected and autonomous vehicles (CAV) to achieve high level position accuracy that is needed for driving (e.g. approx. 30 cm accuracy for lane position). By using 5G network assistance, this accuracy can be achieved over the wide coverage area expected to be available from 5G networks. This will also enable positioning to be maintained in locations where GNSS signal is poor, such as in dense city with high buildings.

Automotive use cases for 5G Precise Positioning are expected to include the provision of enhanced location information through Sidelink positioning, as well as for network mode based 5G positioning. The network mode may be used as an important element in safety and autonomous driving in scenarios where direct line of sight to multiple satellites is not possible (e.g. in a tunnel or parking facility, or an urban canyon with high rise buildings). The 5G network coverage may still be possible in many of these circumstances, and may be augmented with other position information such as RTK to provide accurate position estimates.

Several industry bodies in the automotive industry are working to provide requirements and technology for 5G Precise Positioning. Organizations such as SAE (Automotive Industry Standards group based in the USA) and 5GAA (Car OEM's, Network Operators, and related supply chains) provide inputs that create requirements towards 3GPP for the development of specific 5G features in the 3GPP specifications. The industry activity also includes ETSI (European Technical Standards Institute), leading in the topic of automotive ITS standards for Europe, and RTCM (Radio Technical Commission for Maritime Services) that provide US standards for Differential GNSS systems, where a supplementary signal from a known precise location is used to enhance GNSS positioning capability.

Test Requirements and Methodologies

Reference Signals

The basic principle is that this is transmitter side testing, and the need is to verify that the correct resource elements and power levels have been selected by the transmitter and then correctly configured and transmitted.

The Reference Signals for downlink (Positioning Reference Signal) and for uplink (Sounding Reference Signal for positioning) are defined in 3GPP in terms of relative power level, modulation format, and the relevant Resource Elements (Time and Frequency domain mapping) to be used by the Reference Signals. In testing of these it is required to verify the correct implementation of power, frequency and time by using a Test Equipment that decodes the Resource Blocks and then presents the power level of the related Resource Elements (and can calculate the relevant resource elements to be used by the reference signals).

Signal Analyzer MS2850A

A Vector Signal Analyzer (such as Anritsu MS2850A) can be used to capture the output of a 5G transmitter and to then display the contents of each frame or resource block. Within this the specific Resource Elements relating to the expected Reference Signals can be checked for correct power level and format.

UE Measurements and Reports

The basic principle here is that this is receiver and associated signal processing test, with the verification by means of verifying the correct response messages (containing the measurement information) are sent in the uplink by the UE.

Radio Communication Test Station MT8000A

For this type of testing, a Network Simulator (such as Anritsu MT8000A) can be used to generate the downlink signal containing the relevant Positioning Reference Signals with a known power level and position in the resource blocks. Control plane messages can then be configured and sent from the Network Simulator to the UE to instruct it to make positioning measurements and report them back to the gNB. The Network Simulator will then receive the measurement reports from the UE and can verify that the contents of the measurement report are correct and are corresponding to the downlink Positioning Reference Signal conditions that were created such as power level, timing, AWGN noise level, etc. (Note, it may also be possible to extract this information direct from the UE if internal logging tools for the UE are available).

In addition to the above functional testing, the UE may also be verified using Protocol Conformance Test procedures. These are a standardised set of protocol message sequences that can verify the correct format and sequence for the messages sent to/from the UE. There are also a set of Conformance Test procedures to verify the accuracy of the different measurement procedures. The Protocol Conformance Test procedures for GNSS based UE positioning are found in 3GPP TS37.571, although currently only supporting LTE (E-UTRA) procedures and not updated for the 5G NR procedures. These test cases also extend the coverage of the testing scope to also include the GNSS signals, to verify the correct reception and processing of both the Cellular and GNSS information, and to verify the processes where the Cellular information is used to assist or enhance the GNSS based position calculations. For this reason, these test cases also include the use of a GNSS simulator to provide the exact GNSS signals and conditions needed to test the UE functionality.

RAN Measurements and Reports

The basic principle here is that this is receiver and associated signal processing test, with the verification by means of verifying the correct measurement reports are sent by the RAN to the Positioning Server in the Core Network (sent to the AMF using the N2 interface, which will forward the messages to the LMF using the NL1 interface).

For this type of testing, a real UE (or UE simulator) is used to generate the uplink Reference Signals, and a channel emulator is used to control the power level and timing of the signal received into the gNB. A protocol analyser is then connected to the N2 interface from the gNB and will extract the messages which are destined for the LMF. The contents of these reports can then be verified against the expected results based on channel emulation settings. (Note, it may also be possible to extract this information direct from the gNB if internal logging tools for the gNB are available).

In addition to the above tests, there are further 'functional tests' that are specified by various industry bodies (e.g. Open Mobile Alliance, OMA) and Mobile Network Operators, to simulate 'real life' scenarios for the system to provide accurate location information. These scenarios usually extend the scope of the UE testing to include further variations on GNSS signal conditions, and network conditions, to cover use cases beyond those of the 3GPP Conformance Testing. This is usually to cover scenarios and use cases which are specific to the Mobile Network Operator or to the specific network configuration they have chosen to deploy.

3GPP Precise Positioning Market and Eco-system within the Industry

The eco-system for the deployment of 5G Precise Positioning technology is still in the phase of establishing use case specific needs and plans. The main industry players within the eco-system are as follows:

• Mobile Network Operators (MNO's)

They are currently in the process to estimate network deployment schedules. This schedule is built upon the maturity of eco-system both from the network infra-structure side, the device side, and the business model for generating revenue. Although it can appear that the MNO is following the establishment of capability in the eco-system, the MNO is often the driving force that creates demand within infra-structure vendors and device vendors. Once the capabilities are established within 3GPP specifications, and trials have proven the technical deployment feasibility, then the key issue for launch is the business model suited to each industry segment/vertical.

• Infra-structure Vendors

The features of 5G precise positioning are built upon new signalling capabilities in the RAN and new software functions in the Core Network. So no new physical entities are required and the feature development is a software task. Infra vendors are first building demonstrators and trials platforms to test and prove the new features, before a widespread commercial launch. Once the 3GPP specifications are fixed for each release, the network capability is driven by the MNO's required time to market.

• Chipset Vendors (cellular and GNSS capability)

Chipset vendors have started to publicly demonstrate capability and 'proof of concept' for the Release 16 capabilities, and are engaging industry verticals with trials and evaluations. As with the infra-structure vendors, the features are mainly software driven. For UE 'stand alone' features then the data fusion of GNSS plus 5G NR plus other sensor data is the key element for the chipset implementation, and is closely linked to the overall use case and SmartPhone/module design. For RAN/network supported features then the chipset is mainly concerned with the measurement and reporting of the 5G NR Position signals and measurements. For this segment there is high focus on testing the core functionality, standards compliance, and basic performance (location accuracy, time to fix, power consumption) to optimise the base platform.

• Premium Tier Smartphone Vendors

The SmartPhone vendors supply a 'complete platform' with the 5G NR chipset, GNSS, other sensor data (e.g. Bluetooth, Wi-Fi, Barometric, RTK accelerometers) all integrated to a single platform. The Smartphone platform must also integrate all functions into a single operating system (e.g. Android or iOS) and expose the functions in a useable way for App developers. This requires a highly integrated approach to the sensor fusion and location estimation, combined with a simple and scalable control interface (API) that can be easily used across many App developers. For this segment, there is a high demand for testing of the integrated solution with multi-sensor information.

• IoT Module Vendors

The IoT module vendors are tasked to integrate the Cellular Chipsets, GNSS functions, and other sensor data into a complete module solution to be deployed in single or multiple use cases. Whilst the critical capability of 5G NR positioning is already provided by the chipset vendors, the module vendors have a focus towards the overall data integration and achieving the required performance level and control interfaces to make the function useable and attractive to the different industry verticals.

• Industry Vertical Automotive

The automotive segment is currently evaluating 5G NR Precise Positioning to enhance the position accuracy in areas of poor GNSS coverage (e.g. tunnels, underground parking, urban canyons) as a feature to support autonomous driving and V2X safety applications. Also, the autonomous driving use cases may require high position accuracy (e.g. 20 cm accuracy to locate a vehicle into the centre of a designated lane) and in many scenarios GNSS can not provide such accuracy (e.g. 2 m accuracy), so 5G NR is evaluated as part of the sensor fusion capabilities to provide enhanced position accuracy in supplement to GNSS.

• Industry Vertical Smart Factory

The industrial Smart Factory segment has a clear interest in 5G NR precise positioning, so provide accurate position information inside a factory or warehouse building where GNSS signal is not available (no line of sight to satellites). As the Smart Factory eco-system is evaluating the use of 5G NR for Private 5G Networks to provide wireless connectivity into a factory or warehouse, then the addition of precise positioning capability to this network capability becomes a very relevant and attractive use case.

Note

Advancing beyond

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