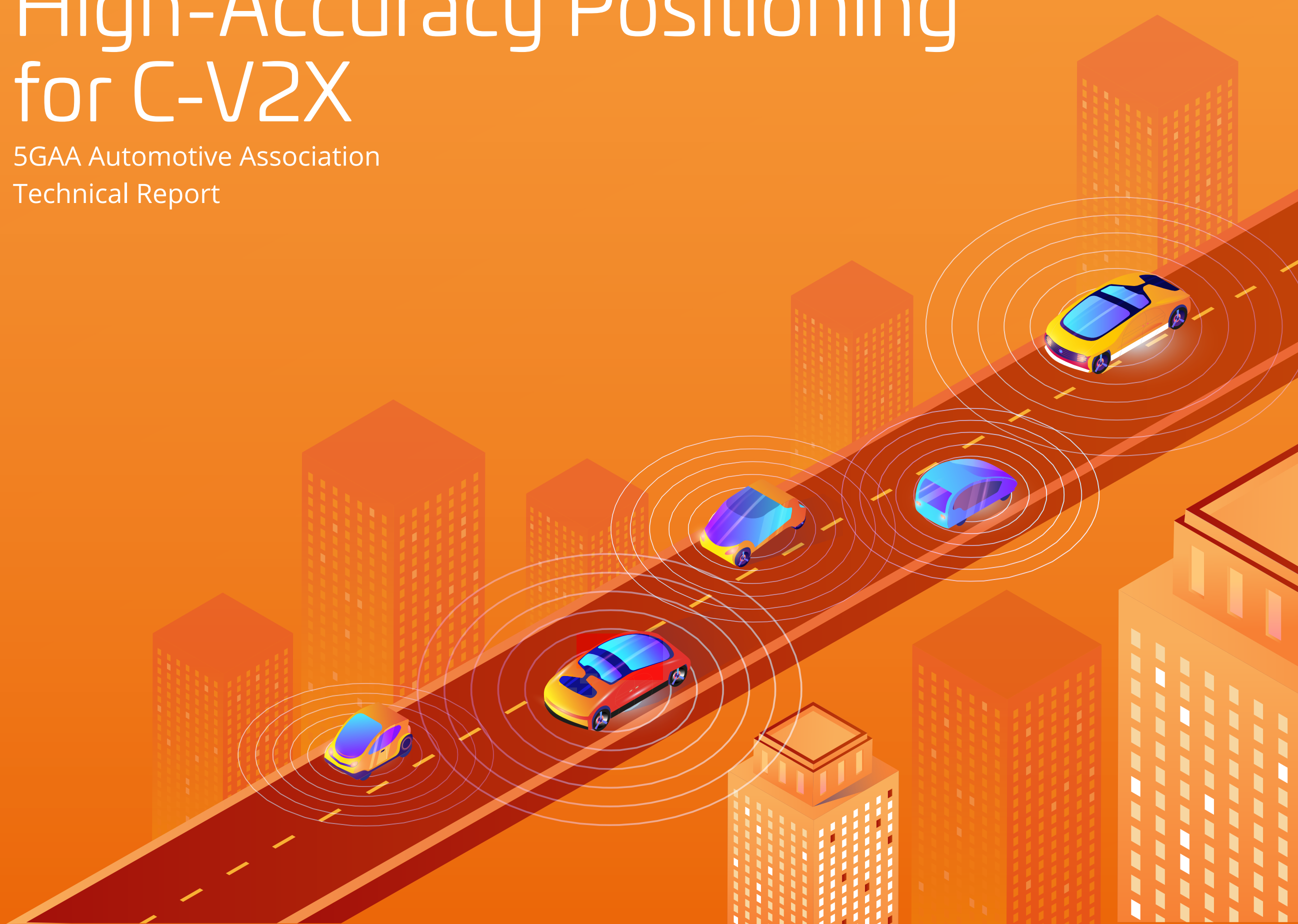
System Architecture and Solution Development; High-Accuracy Positioning for C-V2X

5GAA Automotive Association
Technical Report



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Foreword

This Technical Report has been produced by 5GAA.

The contents of the present document are subject to continuing work within the Working Groups (WG) and may change following formal WG approval. Should the WG modify the contents of the present document, it will be re-released by the WG with an identifying change of the consistent numbering that all WG meeting documents and files should follow (according to 5GAA Rules of Procedure):

x-nnzzzz

(1) This numbering system has six logical elements:

(a) x: a single letter corresponding to the working group:

where x =

T (Use cases and Technical Requirements)

A (System Architecture and Solution Development)

P (Evaluation, Testbed and Pilots)

S (Standards and Spectrum)

B (Business Models and Go-To-Market Strategies)

(b) nn: two digits to indicate the year. i.e. ,17,18 19, etc

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(2) No provision is made for the use of revision numbers. Documents which are a revision of a previous version should indicate the document number of that previous version

(3) The file name of documents shall be the document number. For example, document S-160357 will be contained in file S-160357.doc

1 Scope

The present document aims to study the requirements of positioning, build understanding of the positioning system framework, and offer the corresponding technologies according to the requirements and environments, as well as some demonstrations in High-Accuracy Positioning for Vehicle-to-Everything (V2XHAP) services.

2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.
- For a specific reference, subsequent revisions do not apply.
- For a non-specific reference, the latest version applies.

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3 Definitions, symbols and abbreviations

3.1 Abbreviations

For the purposes of the present document, the following symbols apply:

AL	Alert Limit
Anchor UE	UE such as vehicle, VRU or RSU that participates in sidelink positioning to assist a Target UE’s positioning. The absolute position of the anchor UE is known for the absolute sidelink positioning, but it is not necessary for the relative sidelink positioning.
AOA	Angle-of-Arrival
AOD	Angle-of-Departure
CRLBs	Cramer-Rao Lower Bounds
DAS	Distributed Antenna Systems
DSMP	Dedicated Short Message Protocol
eNB	Evolved Node B
E-SMLC	Enhanced Serving Mobile Location Center
GNSS	Global Navigation Satellite System
IoV	Internet of Vehicles
IMU	Inertial Measurement Unit
ITRF	International Terrestrial Reference Frame
KPI	Key Performance Indicator
LCS	Location Services
LiDAR	Light Detection and Ranging
LMU	Location Measurement Unit
LOS	Line of Sight
LPP	LTE Positioning Protocol
MEC	Mobile Edge Computing
MME	Mobility Management Entity

mmWave	Millimetre Wave
NR	New Radio
NTRIP	Networked Transport of RTCM via Internet Protocol
OSR	Observation Space Representation
OTDOA	Observed Time Difference of Arrival
PL	Protection Level
RMa	Rural Macro
RSTD	Reference Signal Time Difference
RSU	RoadSide Unit
RTCM	Radio Technical Commission for Maritime services
RTK	Real-Time Kinematic
RTT	Round Trip Time
SIB	System Information Blocks
SLA	Service Level Agreement
SLAM	Simultaneous Localisation and Mapping
SLP	Service Location Protocol
SSR	State Space Representation
S-PRS	Sidelink Positioning Reference Signal
SUPL	Secure User Plane Location
TDOA	Time Difference of Arrival
TIR	Target Integrity Risk
ToA	Time of Arrival
Target UE	The UE being positioned
UE	User Equipment
UTDOA	Uplink Time Difference of Arrival
V2X	Vehicle-to-Everything
V2XHAP	Vehicle-to-Everything High-Accuracy Positioning
VRU	Vulnerable Road Users
WSMP	Wave Short Message Protocol

4 Overview of high-accuracy positioning

4.1 Overview

Vehicle-to-Everything (V2X) promotes automated driving and enhances the traffic experience. The connection between cars, infrastructure, network as well as pedestrians enables a much more efficient and safer transport system. As one of the key components in V2X services, positioning information is indispensable to V2X use cases, such as assisted driving, automated driving, traffic monitoring and management, autonomous parking, etc.

There are multiple use cases involved in V2X services; emergency brake warning, pre-crash sensing warning, road hazard warning, congestion alert, speed guidance, automated driving, remote driving, etc. According to the different requirements for V2X use cases, the positioning accuracies are also different. As defined in the use cases in WG1, positioning accuracy is involved as a service level key performance indicator (KPI) [1]. For instance, the positioning accuracy requirement for remote driving is 0.1m [2], while it is 30m for the in-vehicle entertainment [3]. More examples can be found in 3GPP, such as 22.885 [4], 22.886 [5], 22.872 [7], etc. The Positioning accuracy requirements in typical use cases have been summarised in WG1 [6]. But some cognitive differentiations exist in different organisations. Therefore, it is essential for 5GAA to build a uniform understanding of the positioning requirements for different use cases to help set up the positioning systems framework.

With the evolution of V2X services from assisted driving to automated driving, the use case requirements are also changing in terms of the availability of network coverage, level of uncertainty, availability of features for simultaneous localisation and mapping (SLAM)-based positioning techniques, reliability, latency, speed, data rate, communication range, as well as positioning accuracy, which is changing from metre level to sub-metre level. Different from other services, positioning information is one of the essentials to guarantee the safety of Internet of Vehicles (IoV). Some important KPIs for positioning have been described in 3GPP [7], such as positioning accuracy, latency, update rate, power consumption, etc. Furthermore, there are some specific needs in terms of V2X service scenarios, such as continuity, reliability, and security/privacy, etc. All positioning KPIs for V2X mentioned above need to be clarified, especially positioning accuracy which is the most basic requirement in V2X service. In some use cases, such as automated driving, remote driving and platooning, centimetre-level positioning with stable performance provides the necessary accuracy and safety assurance.

The positioning schemes vary according to the positioning requirements and environments. GNSS or its differential complement Real-time Kinematic (RTK), is the most basic positioning method. Considering that GNSS is not available in some scenarios such as tunnels or dense urban areas, its application is limited to the outdoor environment. With appropriate corrections, GNSS should be studied as one of the positioning solutions for C-V2X. Positioning based on sensors is another common method for vehicles. However, the high costs and vulnerability to the environment also limit its application prospects. Generally, one single technology such as GNSS or sensors is hard to satisfy the actual requirements to guarantee the positioning performance for C-V2X. The high- accuracy positioning techniques should be supported by some other assistive methods, inertial navigation, or HD map to ensure the positioning accuracy. The cellular network is essential to enhanced positioning performance, such as the transmission of GNSS assistance data (e.g. RTK and State Space Representation, or SSR) and the sensor data, HD map download and even the fusion of the positioning data, etc. Sidelink positioning is another technique to improve vehicle positioning, where a positioning reference signal transmission and measurement are performed on sidelink. Moreover, cooperative positioning, antenna/RSU deployment technique and synchronisation are also methods to enhance positioning capabilities.

5 Positioning requirements and challenges for C-V2X

5.1 Positioning requirement indicators in different scenarios for C-V2X

There are three kinds of services contained in C-V2X; traffic safety, traffic efficiency and information services. Different services have different positioning indicators. Meanwhile, as a kind of mobile entity, vehicles will experience various service scenarios, such as highways, urban roads, closed parks, and underground garages. Different technical requirements for positioning are also defined in each service scenarios. Typical traffic safety services contain intersection collision warning and emergency brake warning, etc.; typical traffic efficiency services contain speed guidance and emergency vehicle avoidance, etc.; typical information services contain near-field payment and dynamic map downloading, etc. Table 5.1-1 shows these typical V2X service requirements for positioning.

Table 5.1-1: Main service scenarios and positioning indicators for C-V2X [8]

Use Cases/Requirements	Velocity (km/h)	Vehicle Density (units/km^2)	Positioning Accuracy (m)
Cross-Traffic Left-Turn Assist	120	1500	1.5 (3σ)
Intersection Movement Assist	120	12000	1.5 (3σ)
Emergency Break Warning	250	12000	1.5 (3σ)
Traffic Jam Warning – Urban Scenario on Road Warning	70	12000	20 (1σ)
Traffic Jam Warning – Rural Scenario on Road Warning	120	9000	20 (1σ)
Traffic Jam Warning – Highway Scenario on Road Warning	250	4500	20 (1σ)
Rural Scenario en Route Information	120	9000	20 (1σ)
Highway Scenario en Route Information	250	4500	20 (1σ)
Lane Change Warning – Lagging Vehicle, Leading Vehicle, Highway	RV: 120 HV: 100	4500	1.5 (1σ)
Lane Change Warning – Lagging Vehicle, Leading Vehicle, Urban	RV: 40 HV: 50	12000	1.5 (1σ)
Lane Change Warning – Not Permitted Case, Rural	83	9000	1.5 (1σ)
Software Update – Conventional-Routine/Urgent, Autonomous-Routine	70	1500	30 (1σ)
Software Update – Autonomous-Urgent	250	1500	30 (1σ)
Software Update – Without infrastructure, vehicle to workshop	0	1500	50 (1σ)
Vehicle Health Monitoring	250	1200	1.5 (3σ)
Real-time High-Definition Maps			
Speed Harmonisation	Highway: 250 Rural: 120 City: 70	12000 (urban)	1.5 (3σ)
High-Definition Sensor Sharing	250	12000	0.1 (3σ)
See-Through for Pass Manoeuvre	120	9000	1.5 (3σ)
Vulnerable Road User – Awareness Near Potentially Dangerous Situations	Urban: 70 Rural: 120	Concerned VRUs: 300 Present VRUs:	1 (3σ)

		10000 Vehicles: 1500	
Vulnerable Road User – Collision Risk Warning	Urban: 70 Rural: 120	Concerned VRUs: 300 Present VRUs: 10000 Vehicles: 1500	0.5 (3σ)
Real-Time Situational Awareness and High-Definition Maps	250	1500	0.5
Group Start	70	3200	0.2 (3σ)
Tele-Operated Driving (TOD)	50	10	0.1 (3σ)
TOD Support	10	10	0.1 (3σ)
TOD for Automated Parking	20	100	0.1 (3σ)
Obstructed View Assist via CCTV	10	10000	2 (3σ)
Obstructed View Assist via Remote Vehicles	100	10000	1.5 (3σ)
Cooperative Manoeuvres of Autonomous Vehicles for Emergency Situations	Urban: 70 Rural: 120 Highway:	4500 (Highway) 9000 (Rural) 12000 (Urban)	0.2 (3σ)
Continuous Traffic Flow via Green Lights Coordination	70	3200	1.5 (3σ)
Remote Automated Driving Cancellation	250	1500	10 (1σ)
High-Definition Map Collecting and Sharing	City: 70 Highway: 250	12000	0.1-0.5 (3σ)
Automated Intersection Crossing	Urban: 70 Rural: 120	3200 vehicles 10000 VRUs	0.15 (3σ)
HD Content Delivery – High-End Service for Cars	250	500	30 (1σ)
HD Content Delivery – Low-End Service for Cars	150	500	50 (1σ)
HD Content Delivery – Bus Passenger Service	100	30	50 (1σ)
Hazard Collection – Vehicle Collects Hazard and Road Event Information for AV	City: 70 Highway: 250	10000	1.5 (3σ)
Software Update of Reconfigurable Radio System	70	1500	30 (1σ)
Vehicles Platooning in Steady State	100	4500 (Highway) 9000 (Rural) 12000 (Urban)	1.5 (3 σ)
Cooperative Lane Merge	Urban: 70 Rural: 120 Highway: 250	4500 (Highway) 9000 (Rural) 10000 (Urban)	1.5 (3σ)
Autonomous Vehicle Disengagement Report	250	12000	1.5 (3σ)
Patient Transport Monitoring	30	12000	N/A
Accident Report	0	12000	1.5 (3σ)
Infrastructure Assisted Environment Perception – Data Distribution about Objects on the Road	250	1200	0.1 (3σ)

Infrastructure Assisted Environment Perception – Individual Data Transmission in Form of Trajectories or Actuation Commands	120	1200	0.1 (3σ)
Infrastructure-based Tele-Operated Driving	10	1200	0.1 (3σ)
Automated Valet Parking (Wake Up)	0	15150	N/A
Automated Valet Parking – Joint Authentication and Proof of Localisation	25	50	1 (3σ)
Awareness Confirmation	500	9000	1.5 (3σ)
Coordinated, Cooperative Driving Manoeuvre – Cooperative Lane Change	150	12000 for urban 4500 for highways	1.5 (3σ)
Coordinated, Cooperative Driving Manoeuvre – Pedestrian Crossing	120	12000	1 (3σ)
Coordinated, Cooperative Driving Manoeuvre – Road Blockage	120	400	1.5 (3σ)
Cooperative Traffic Gap	50	2000	Longitudinal (absolute): 1.5 (3σ) Lateral (Relative): 1 (3σ)
Cooperative Lateral Parking	5	1000	0.2 (3σ)
Cooperative Curbside Management	80	2000	1 (3σ)
Bus Lane Sharing Request	70	10	1.5 (3σ)
Bus Lane Sharing Revocation	70	10	1.5 (3σ)
Vehicle Decision Assist – RV Waiting for a Short Period of Time, RV Broken Down, Bus Having to Wait	250	1000	1.5 (3σ)
Vehicle Decision Assist – Slow Vehicle en Route	250	10000	1.5 (3σ)

Automated driving has gradually become integrated into people's lives as a typical C-V2X service, such as a pilotless ferry, pilotless cleaning, pilotless delivery in the closed or semi-enclosed park, and pilotless mining and transportation in the mining area. High-accuracy positioning is the basic premise for automated driving and remote driving. Therefore, its performance requirements are extremely precise.

With respect to Level 4 and 5 automated driving (SAE International), the positioning requirements will vary for different use cases depending on which conditions need to be satisfied. For example, in the 5GAA C-V2X Whitepaper [18], the recommended positioning accuracy for Hazardous Location Warnings and Lane Change Warnings is 1.5m at the 3-sigma level (99.7 percentile). Both use cases are defined as safety-critical functions for autonomous vehicles and share a common requirement of 1.5m to identify which lane the vehicle is travelling in. This baseline requirement of 1.5m, lane-level accuracy, is common across various other use case studies [18] (e.g. intersection movement assistance, cross-traffic assistance, emergency brake warning, etc.), making it an important objective for safety-critical positioning. In the context of V2XHAP [12], safety-critical functions for positioning are directly linked to the KPIs on reliability, alarm thresholds and early warnings, which are collectively known as 'positioning integrity' [19], [20], [21], [22], [23].

The concepts of positioning integrity in support of C-V2X and automated driving apply in the following ways. Firstly, the upper bound of 1.5m described above is known as the Alert Limit (AL) – the maximum allowable position error that cannot be exceeded without alerting the user. The AL depends on the Target Integrity Risk (TIR) for a given use case, where TIR is the allowable rate of occurrence beyond the AL (e.g. a TIR<10^{-7} would represent less than 1 failure every 10 million hours of driving). When the location accuracy of a reported position is estimated on a user device, typically at the 2-sigma level (95th percentile) or higher, it can be validated against the AL. However, while the estimated accuracy gives a useful indicator of typical system performance, the concept of integrity is required for safety-critical applications, to provide a more stringent guarantee of performance. This raises the fundamental concept of Protection Levels (PL).

In essence, to accommodate very high levels of integrity for safety-critical systems, the sources of error which have a much lower rate of occurrence than would normally be addressed by the location accuracy, need to be considered (e.g. low occurrence threats include satellite orbit errors or cycle slips in the case of GNSS). Importantly, these errors can be difficult to detect on the user device alone, meaning the ability to flag and monitor their presence requires a combination of network-side and device-side positioning processes [19], [20], [21]. The resulting estimate is an instantaneous error bound known as the PL, which is needed to validate whether the estimated position is within the AL. Naturally, the PL constantly changes in real time depending on the environment and conditions in which the receiver is operating, such as on an open highway, in a dense urban setting, in tunnels, etc.

It follows that the positioning requirements for C-V2X and L4/L5 automated driving will vary depending on the intended use case. For example, a typical set of requirements for an open highway scenario (adapted from [18] and [23]) is provided in Table 5.1-2, noting that no parameters are included for PL or TIR given these requirements depend on the integrity qualification strategies and system design implemented by vehicle manufacturers and positioning service providers.

Table 5.1-2: Requirements for positioning on L4/L5 automated driving

Requirement	Indicators	Value
Location Accuracy	95th Percentile (2-sigma)	< 30cm
Location Integrity	Alert limit	< 1.5m
Attitude Accuracy	Error mean	< 0.5 degree
Attitude Robust	Maximum error	< 2.0 degree
Scenarios	Covered scenarios	All-weather, open highway

Finally, burgeoning demand for trusted, high-accuracy positioning in support of automotive and mobility use cases has created a complex set of requirements which are the subject of extensive research and investment by commercial positioning providers and OEM partners [18], [21], [23]. Commercial integrity solutions exist, but there is no industry standard for distributing integrity assistance data. Having recognised these technology developments and market opportunities, a new work item [21] was approved in 3GPP Release 17 to study and define integrity KPIs and information elements for positioning integrity, via the new radio (NR) network and user equipment specifications.

The NR Positioning Enhancements study [21] will be a crucial input towards achieving the required positioning performance for C-V2X and L4/L5 applications [12], [18], [23], meaning 5GAA should play a key role in helping to define and validate the required use cases.

5.2 Positioning challenges for C-V2X

Currently, positioning requirements in C-V2X scenarios mainly meet the following two challenges: positioning requirements in different application scenarios and the cost of high-accuracy positioning.

- To meet positioning requirements in different application scenarios, outdoor positioning technology is currently mainly based on RTK, which can achieve centimetre-level positioning in an open and unobstructed scenario. However, considering intensive buildings in the urban environment, as well as the occlusion scenes such as tunnels/viaducts/underground parking, it needs to be combined with the inertial unit to maintain accuracy over a continuous period of time by using fusion algorithms. Therefore, how to ensure stable, long-term high-accuracy positioning of the vehicle in all scenarios is a great challenge in C-V2X application scenarios. It is necessary to ensure the positioning accuracy of the vehicle anytime and anywhere through multi-source data fusion, combining the cellular network positioning, inertial navigation, radar, camera, etc. (e.g. path planning and lane-level monitoring in C-V2X services require corresponding/matching high-accuracy maps to ensure positioning accuracy).

- To ensure the performance requirements of high-accuracy vehicle positioning, it is necessary to integrate cellular networks, satellites, inertial navigation, cameras and radar data. However, drawing HD maps is costly and complex, and requires regular updates to ensure positioning performance and service requirements. High cost and a lack of popularity limits the business services of high-accuracy positioning.

6 System architecture for V2X high-accuracy positioning

With the rapid development of 5G and C-V2X, services are rapidly expanding to meet the demand. Combining the scenario analysis and performance requirements, high-accuracy positioning – as a key part of the whole C-V2X system – can be divided into UE-based positioning architecture and UE-assisted positioning architecture.

6.1 UE-based positioning architecture

UE-based positioning is where the positioning calculation is completed at the terminal side by using the positioning information' provided by the network such as RTK, map data, etc.

UE-based functions are shown in Figure 6 1-1. For the network, it is mainly used for RTK correction data transmitting and 5G-dependent positioning. And for the terminal, it is mainly used on RTK positioning and fusion algorithms.

Assisted information for positioning can be obtained through eNB/gNB/RSU. With RTK information broadcasting through the RSU or base station, whose position is known, the initial position information reporting by the terminal can be avoided. This is the same for GNSS positioning techniques using the SSR scheme, which do not need the terminal to report the initial positioning information. Meanwhile, collection and combination of information increases the terminal complexity.

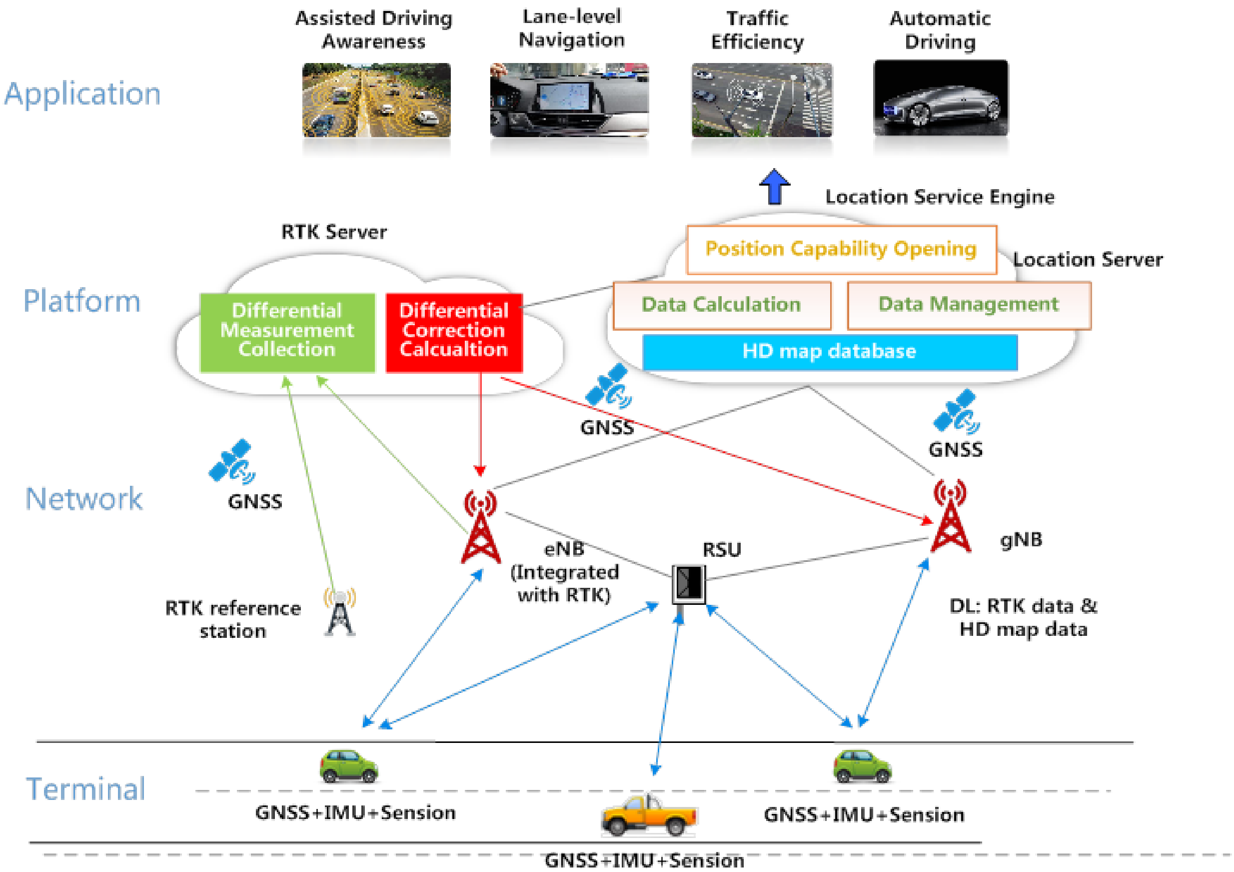


Figure 6.1-1: UE-based positioning architecture of V2X system

UE-based positioning architecture includes terminal, network, platform and application functional blocks, as shown in Figure 6.1-1. The terminal functional block implements multi-source data fusion (satellite, sensor and cellular network data) algorithms to ensure the positioning requirements of different services and scenarios. The platform functional block provides positioning for integrated vehicles, including RTK differential decomposition computing capability, map database, and dynamic HD map, positioning engine, and open positioning capability. The network functional block includes 5G BS, RTK reference station and RSU to provide reliable data transmission for the positioning terminal. Based on the high-accuracy positioning system, the application functional block can provide services such as lane-level navigation, line planning and automated driving.

- **Terminal functional block**

  To meet the high-accuracy positioning requirements of vehicles in different environments, it is necessary to adopt a positioning scheme mixing multi-source data in the terminal, including differential data-based GNSS positioning data, inertial navigation data, sensor data, HD map data, and cellular network data, etc.

- **Network functional block**

  This block mainly implements signal measurement and information transmission, including the deployment of 5G BSs, RTK reference stations, and RSU roadside units. As a new generation of communication technology, 5G ensures a high data transmission rate to meet the requirement of real-time transmission on high-precision maps. 5G BS can also complete the signal measurement with the terminal and report platform. This platform computes the positioning values based on 5G signals to provide assistance for high-accuracy positioning of vehicles. Based on 5G MEC, real-time updates can be realised on the HD map. Real-time performance and accuracy will be greatly improved.

  The RTK reference station is mainly used for RTK measurement, and can be co-constructed with the operator BS, which will greatly reduce the cost of network deployment, operation and maintenance. Meanwhile, the measurement data transmission of the RTK reference station can be realised through the 5G network. It will help with deploying the reference station quickly and flexibly.

  The RSU can deliver RTK information broadcasting, which avoids the reporting of the terminal's initial location in the traditional RTK positioning. Meanwhile, RSU provides local road lane-level maps and real-time dynamic traffic information broadcasts.

- **Platform functional block**

  The platform functional block can be modularised, including:

  HD map database: Static HD map information includes lane lines, lane centre lines, lane property changes, etc. It also includes road parameters such as curvature, slope, heading, and slope, which enables the vehicle to accurately turn, brake, climb, etc. It also includes road signage such as traffic and road signs, and special points such as areas where the GPS disappears or there is road construction status reported.

  Dynamic traffic information: This includes road traffic conditions, construction conditions, traffic accidents, traffic control, weather conditions, etc.

  Difference correction calculation: Platform continuously receives satellite data through RTK BS and optimises various major system error sources such as ionospheric error, tropospheric error, orbit error and multipath effect, and establishes the error model of ionospheric delay and tropospheric delay for the whole network. Optimised spatial error will be sent to the vehicles.

  Data management: This includes national administrative division data, vector map data, basic traffic data, massive dynamic emergency rescue vehicle position data, navigation data, real-time traffic data, POI data, etc. (all operating data integrated and compiled after the production process).

  Data calculation: This includes path planning, map static data calculation, dynamic real-time data calculation, big data analysis, data management and other functions.

- **Application functional block**

  The application functional block provides users with services such as map browsing, planning route display, data monitoring and management functions, as well as other location-based car networking services, such as assisted driving and automated driving.

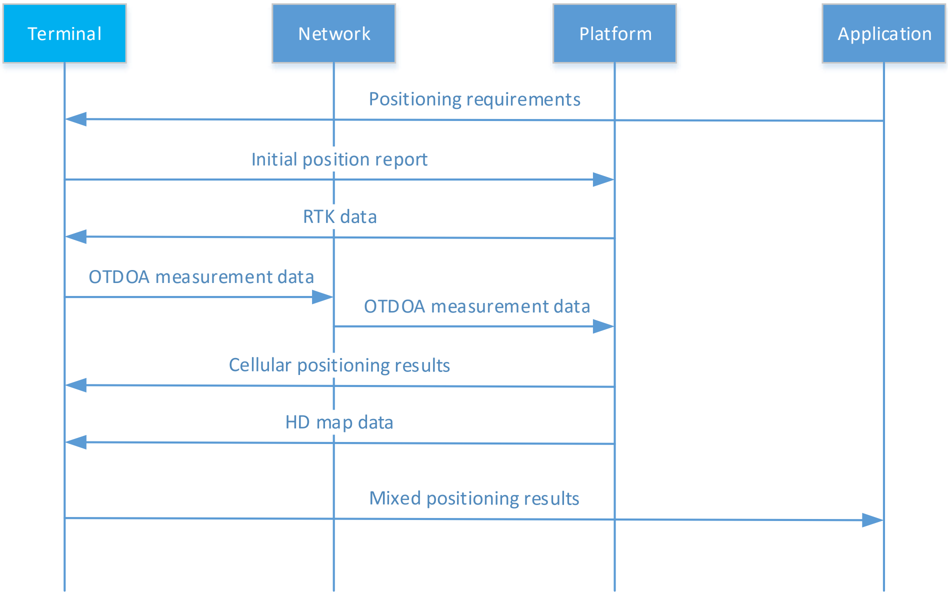


Figure 6.1-2: Example signalling processing in the UE-based positioning architecture

6.2 UE-assisted positioning architecture

UE-assisted positioning calculations are completed on the network side by collecting all the information from both the roadside and terminal side.

UE-assisted functions are as shown in Figure 6 2-1. For the network, it is mainly used on RTK positioning, 5G-based positioning, fusion algorithms and positioning results transmission. For the terminal, it is mainly used on measurement reports and for the receipt of positioning results. And the positioning results can be transmitted to the terminal through eNB/gNB/RSU.

Functional blocks in UE-assisted positioning architecture are similar to UE-based positioning, as shown in Figure 6.2-1. Compared with Figure 6.1-1, the fusion algorithm is deployed at the network functional block, and the calculation can be realised quickly through MEC. Typical UE-assisted positioning scenarios include: VRU and traffic supervision. It decreases the terminal complexity and is suitable for high-precision positioning of pedestrians and non-motorised vehicles in smart traffic.

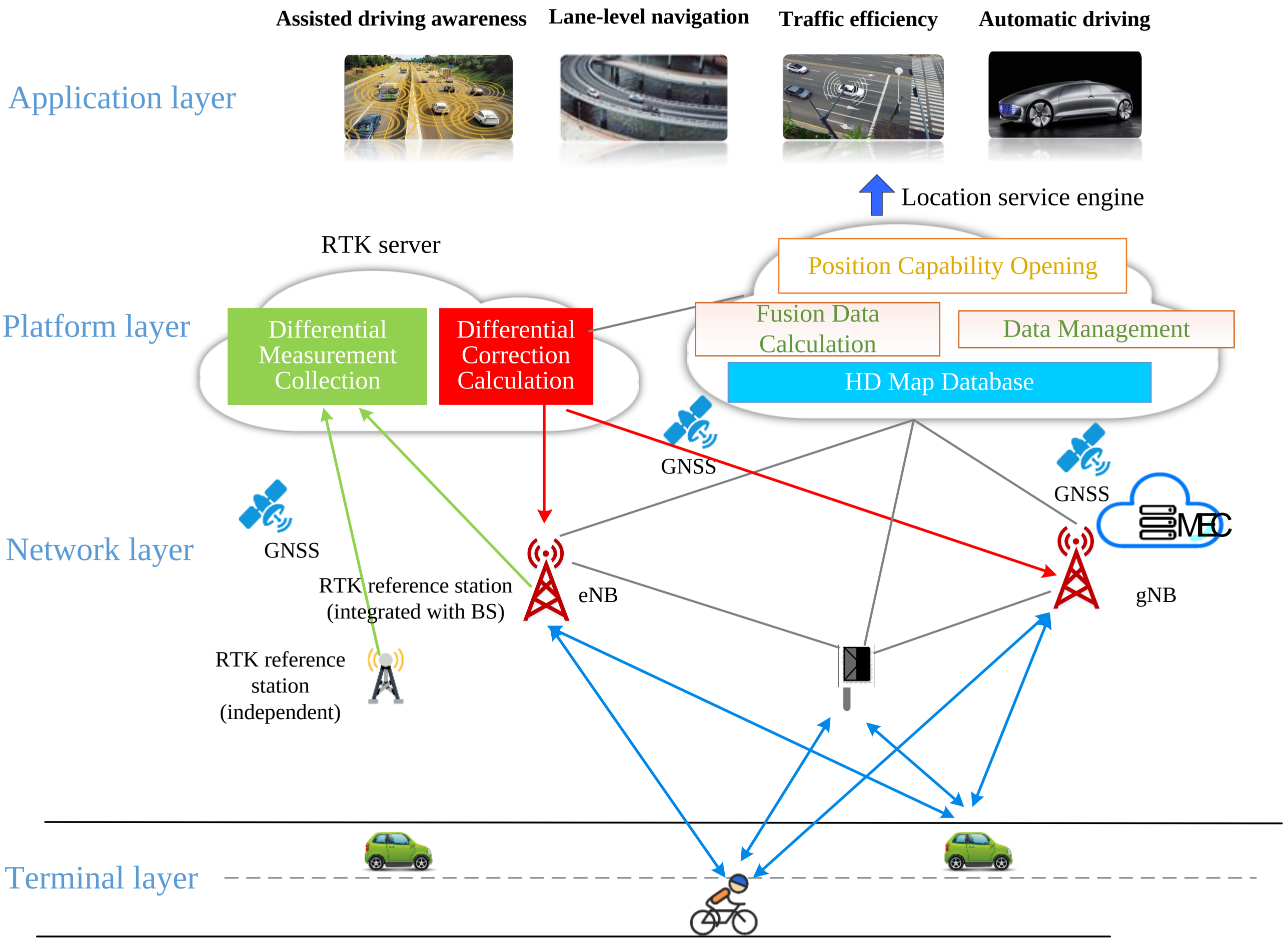


Figure 6.2-1: UE-assisted Positioning Architecture of V2X system

- **Terminal functional block**

  To complete the position calculation on the platform, the terminal needs to transmit the measurement data to the platform including the GNSS data, the sensor data and the inertial navigation data.

- **Network functional block**

  This block mainly implements signal measurement and information transmission, including the deployment of 5G BSs, RTK BSs, and RSU roadside units. As a new generation of communication technology, 5G ensures a high data transmission rate to meet the requirement of real-time transmission on high-precision maps. 5G BS can also complete the signal measurement with the terminal and report platform. The platform computes the positioning values based on the 5G signal to provide assistance for high-accuracy positioning of vehicles.

- **Platform functional block**

  The platform functional block can be modularised, including:

  HD map database: Static HD map information includes lane lines, lane centre lines, lane property changes, etc. It also includes road parameters such as curvature, slope, heading, and slope, which enables the vehicle to accurately turn, brake, climb, etc. It also includes road signage such as traffic and road signs, and special points such as areas where the GPS disappears or there is road construction status reported.

  Dynamic traffic information: This includes road traffic conditions, construction conditions, traffic accidents, traffic control, weather conditions, etc.

  Difference correction calculation: Platform continuously receives satellite data through RTK BS, and optimises various major system error sources such as ionospheric error, tropospheric error, orbit error and multipath effect, and establishes the error model of ionospheric delay and tropospheric delay for the whole network. Optimised spatial error will be sent to the vehicles.

Data management: This includes national administrative division data, vector map data, basic traffic data, massive dynamic emergency rescue vehicle position data, navigation data, real-time traffic data, POI data, etc. (all operating data integrated and compiled after the data production process).

Fusion data calculation: This includes path planning, map static data calculation, dynamic real-time data calculation, big data analysis, data management and other functions. The platform also adopts a positioning scheme mixing multi-source data in the terminal, including differential data based GNSS positioning data, inertial navigation data, sensor data, HD map data, and cellular network data, etc.

- **Application functional block**

The application functional block provides users with services such as map browsing, planning route display, data monitoring and management functions, as well as other location-based car networking services, such as assisted driving and automated driving.

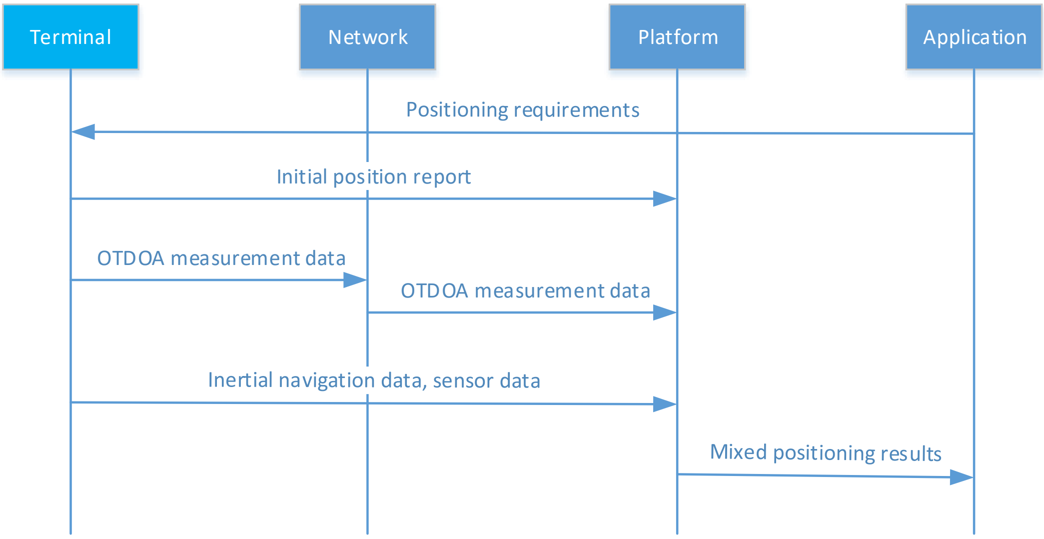


Figure 6.2-2: Example signalling processing in the UE-assisted positioning architecture

6.3 Sidelink positioning architecture

This section describes a sidelink positioning architecture that can be used for providing associated services. The sidelink positioning technology and the relevant architectures were not defined in 3GPP specification, as only Uu link positioning technologies had been developed in 3GPP for radio access technology (RAT)-dependent positioning to date. Note that the S-PRS mentioned in this section is the positioning reference signal transmitted over sidelink. It may be different from PRS specified in Uu positioning in 3GPP.

The sidelink positioning is composed of three operations: the sidelink positioning configuration, the S-PRS transmission and measurement, and the position calculation. The UE-based and UE-assisted positioning architecture in Uu link positioning, as described in section 6.1 and 6.2, can be further sub-categorised in sidelink positioning, depending on the role of the UE and network. Firstly, the sidelink positioning is differentiated from Uu link positioning in that the S-PRS transmission and measurement are done between UEs through sidelink interface. Secondly, the sidelink positioning scheduling and configuration can be controlled by the network (or location server) or the UE that participated in the sidelink positioning process. Applying positioning controllability to both UE-based and UE-assisted positioning architecture, four kinds of architecture can be considered for both absolute and relative sidelink positioning:

1) **UE-configured and UE-based sidelink positioning architecture**

   The ‘target’ UE is the one that wants to know its own position, and the ‘anchor’ is the UE or RSU that participates in sidelink positioning and helps the target UE to acquire its position e.g. by sending/receiving S-PRS and doing relevant measurements.

In this architecture, all three sidelink positioning operations are done by the target or anchor UEs participating in the sidelink positioning process. UEs form a sort of sidelink positioning group and send/receive S-PRS information to calculate the target UE position based on UE measurement. Neither Uu link nor network-based location server is involved in the sidelink positioning process. It is a fully distributed positioning based on the 'positioning group', which can be comprised of a vehicle, VRU and RSU.

In one scenario using this architecture, the anchor UEs (e.g. RSU) can play a role as a location server operated by a road operator, for example.

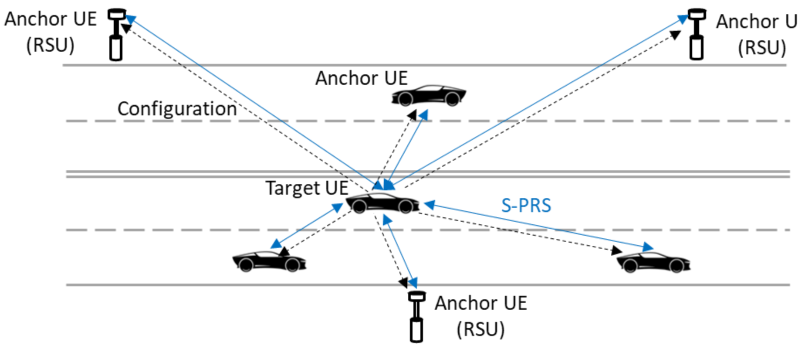


Figure 6.3-1: UE-configured UE-based sidelink positioning architecture

2) Network-configured and UE-based sidelink positioning architecture

The difference between this architecture and the sidelink positioning architecture 1) described above is that the sidelink positioning operations are controlled by the network or the location server. The network can configure which UE will function as a target UE or an anchor UE, when to transmit/receive the S-PRS and using which resources and sidelink positioning method (e.g. sidelink TDOA or RTT, etc.). The remaining operations such as S-PRS transmission/reception, measurement and the position calculation are all done by UEs of the sidelink positioning group.

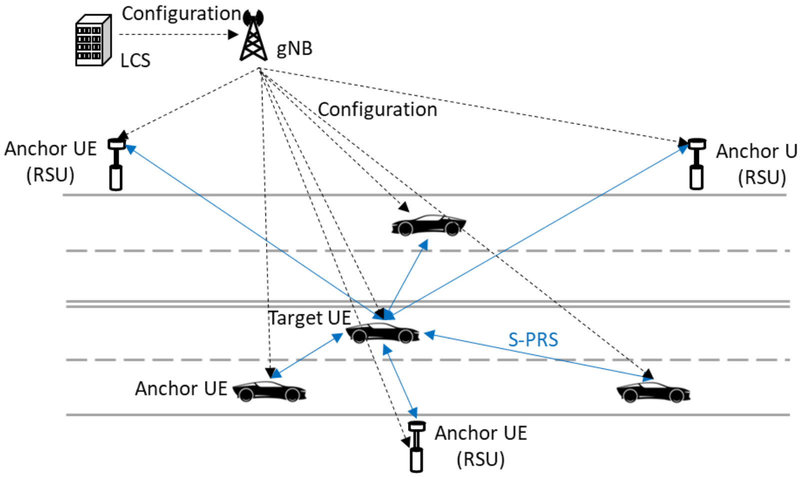


Figure 6.3-2: Network-configured UE-based sidelink positioning architecture

3) UE-configured and UE-assisted sidelink positioning architecture

The main difference between this mode and the sidelink positioning architectures 1) and 2) above is the final positing calculation is done by the network or the location server, rather than the UEs of the sidelink positioning group, as the architecture names implies.

The sidelink positioning configuration, the S-PRS transmission/reception through sidelink and the measurement are done by the UEs of the sidelink positioning group. However, the positioning measurement, such as the RSTD or the angle of departure/arrival is reported to the network, and the final position of the target UE is calculated by the network or the location server. The pros of this architecture are offloading the position calculation to the network side, and a possible ultra-accuracy and faster position calculation based on the powerful processing power of the network. The con is the increased latency to achieve the UE position.

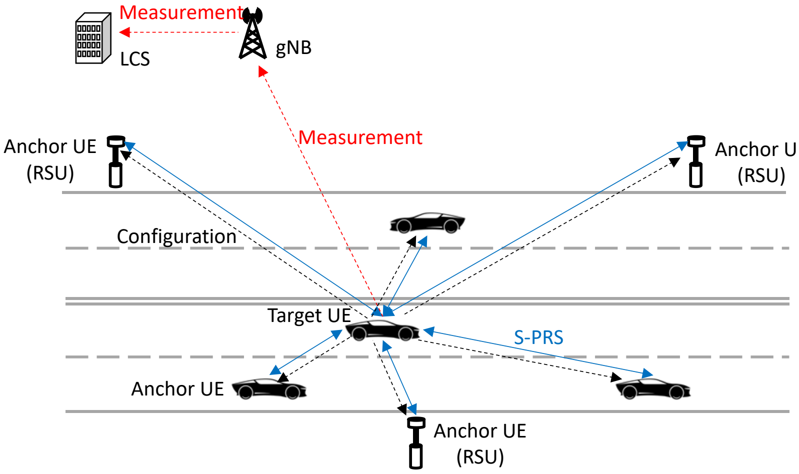


Figure 6.3-3: UE-configured UE-assisted sidelink positioning architecture

4) Network-configured and UE-assisted sidelink positioning architecture

The difference between this mode and the sidelink positioning architecture 3) above is the configuration is controlled by the network or the location server, similar to the sidelink positioning architecture 2) shown above. The position calculation is also done by the network based on the measurement report from the UE. The only operation of UE is the S-PRS transmission/reception and the relevant measurement/reporting. This is the network-configured version of the sidelink positioning architecture (3) above.

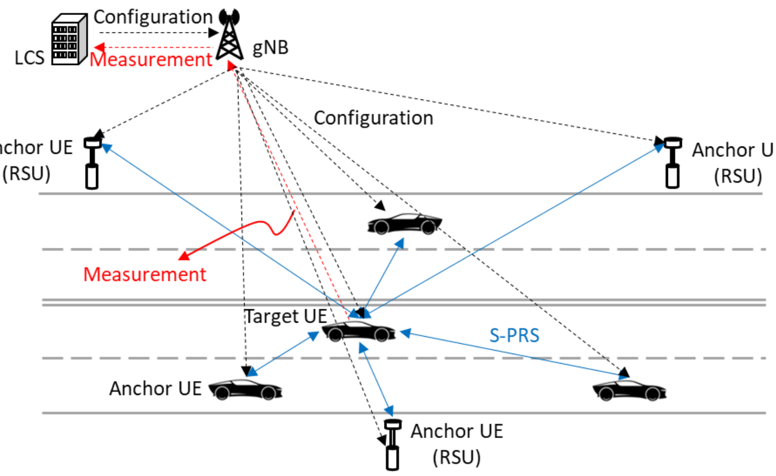


Figure 6-3.4: Network-configured UE-assisted sidelink positioning architecture

Table 6.3-1 summarises the sidelink positioning architectures in relation to the positioning system architectures. Sidelink positioning architecture can also be combined together with GNSS-based or sensor-based positioning.

Table 6.3-1: Sidelink positioning architectures

	Entity of Operation			Positioning Architecture
Sidelink Positioning Architecture Type	Sidelink Positioning Configuration	S-PRS Transmission and Measurement	Position Calculation	
UE-configured and UE-based	UE	UE	UE	UE-based
Network-configured and UE-based	Network	UE	UE	
UE-configured and UE-assisted	UE	UE	Network	UE-assisted
Network-configured and UE-assisted	Network	UE	Network	

From the S-PRS resource allocation point of view, the resources are scheduled by the network in the network-configured UE-based/assisted sidelink positioning architecture, whereas they are autonomously selected by the UE in the UE-configured and -based/assisted sidelink positioning architecture. If gNB schedules S-PRS resources instead of the location server, S-PRS resource allocation will be similar to that used in NR-V2X mode 1 or 2 and LTE-V2X mode 3 or 4.

7 Key technology for high-accuracy positioning of vehicles

7.1 KPIs for high-accuracy positioning

The following KPIs are adapted from TR 22.872 [7]:

- **Position accuracy:** Describes the closeness of the measured position of the UE to its true position value. The accuracy can be either of an absolute position or a relative position. It can be further derived into a horizontal position accuracy – referring to the position error in a 2D reference or horizontal plane, and into a vertical position accuracy – referring to the position error on the vertical axis or altitude.

- **Availability:** Percentage of time when a positioning system is able to provide the required position-related data within the performance targets or requirements.

- **Latency:** Time elapsed between the event that triggers the determination of the position-related data and the availability of the position-related data at the positioning system interface. At initialisation of the positioning system, the latency is also defined as the ‘time to first fix’.

- **Time to first fix (TTFF):** Time elapsed between the first event triggering the determination of the position-related data and the availability of the position-related data at the positioning system interface. TTTF is greater or equal to latency.

- **Update rate:** Rate at which the position-related data is generated by the positioning system. It is the inverse of the time elapsed between two successive position-related data points.

- **System scalability:** Number of devices for which the positioning system can determine the position-related data in a given time unit, and/or for a specific update rate.

- **Continuity:** Likelihood that the positioning system functionality will be available during the complete duration of the intended operation if the positioning system is functioning at the beginning of the operation.

- **Reliability:** Measure of the ability of a positioning system to provide the position-related data under stated conditions for a specified period.

- **Integrity:** 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 UE and/or the user when the positioning system does not fulfil the condition for intended operation.

- **Time to alert:** Time elapsed between a change of the integrity (as defined above) and the information sent to the UE and/or the user.

- **Authentication:** Assurance that the position-related data associated with the UE has been derived from trusted and authorised sources (e.g. real signals and not falsified signals). This KPI is different from security, which defines the measures ensuring that the position-related data is safeguarded against unapproved disclosure or usage inside or outside the positioning system. Because it cannot be summarised and quantified as a scalar target, this KPI is managed as a binary field in the present report: 'yes' or 'no' provision of positioning authentication is needed.

- Security/Privacy: Measures to ensure that the position-related data is safeguarded against unapproved disclosure or usage inside or outside the positioning system and/or to ensure that a non-authorised party cannot access information relating to the privacy of the user. Because it cannot be summarised and quantified as a scalar target, this KPI is managed as a binary field in the present report: 'yes' or 'no' security and/or privacy is needed.

- **Institutional Compliance:** The system must meet the legal and regulatory requirements for the given jurisdictions in which it operates.

> Example: In some regions, according to relevant surveying and mapping regulations, real-time differential service data belongs to controlled management data, and it is necessary to provide services on the basis of user audit and registration. The BS' data centre management department reports user information and the purpose of use to the administrative department, who is responsible for surveying and mapping geographic information at the provincial level or higher, in order to reach better than one metre accuracy. In other regions, commercial service providers deploy and operate their own base station infrastructure end-to-end as part of their service level agreement (SLA) with customers.

- Consistency: Considering that large-scale servers of C-V2X must be based on good interconnectivity, and the terminals connected to C-V2X-related servers need to have a unified standard for the location data, the high-accuracy GNSS correction should also take into account the consistency of data when generating and broadcasting. Inconsistency of data is mainly caused by the inconsistency of coordinate frame of datum point, the imprecision of datum point coordinate of differential reference station, or the difference of solving method of differential correction data.

Therefore, it is not recommended that different reference stations take the 'differential information' coverage around the station independently. Rather, they should use the cloud network solution to eliminate the differences between stations, and the different data solutions. And more backup reference BS should be taken into consideration, to avoid the deviation of positioning data caused by the inconsistency of matching reference BS and operators.

- **Update rate:** Rate at which the position-related data is generated by the positioning system. It is the inverse of the time elapsed between two successive position-related data.

- Power consumption: Electrical power (usually in mW) used by the positioning system to produce the position-related data.

- Energy per fix: Electrical energy (usually in mJ per fix) used by the positioning system to produce the position-related data. It represents the integrated power consumption of the positioning system over the required processing interval. It considers both the processing energy and the energy used during the idle state between two successive productions of position-related data. This KPI can replace power consumption when the positioning system is not active continuously (e.g. device tracking).

- **System scalability:** Number of devices for which the positioning system can determine the position-related data in a given time unit, and/or for a specific update rate.

7.2 GNSS positioning

7.2.1 GNSS location service based on RTK differential system

High-accuracy GNSS enhancement technology implements satellite observation through the ground differential reference station to form differential correction data, and then transmits the data to a flow measurement station through the data communication link, and then the flow measurement station performs the act of 'locating' according to the correction data received.

- The high-precision GNSS differential correction is broadcast to users by the cellular network

  Differential correction data broadcasting on a user plane (internet) is a unicast transmission method based on protocols such as Networked Transport of RTCM via Internet Protocol (NTRIP) and Radio Technical Commission for Maritime services (RTCM). The implementation steps are as shown in Figure 7.2.1-1.

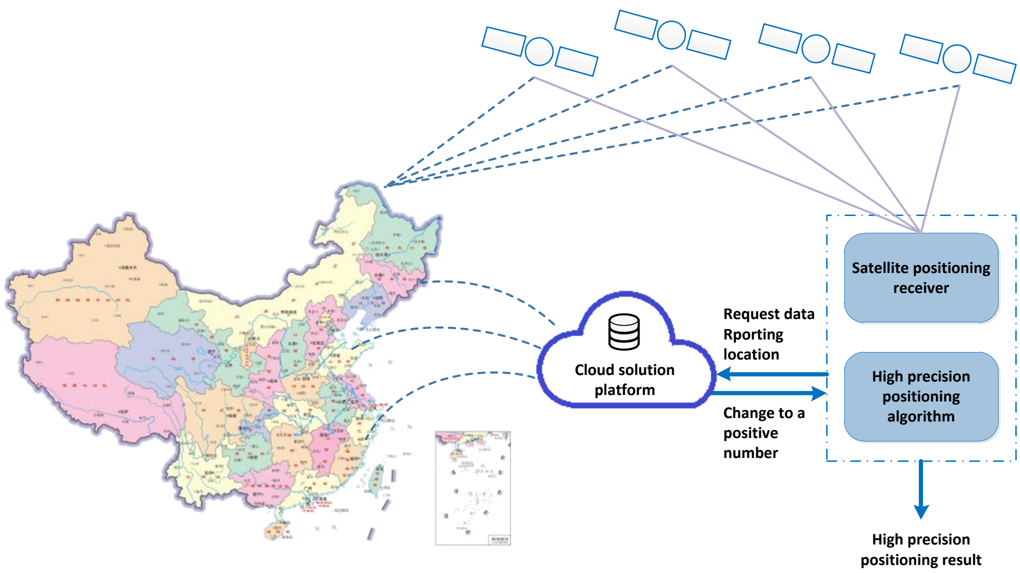


Figure 7.2.1-1: Step of high-precision GNSS differential corrections broadcasting by cellular network

- Observation satellite data from the ground reference station and original satellite observation data are transmitted to the cloud correction calculation and broadcast platform.
- After the cloud correction calculation and broadcast platform receive the original satellite observation data, it begins real-time network modelling and calculation, and forms the 'differential correction' per regional grid.
- Terminal mobile station sends a request for a high-precision correction and reports the initial position obtained by the satellite in its present position.
- Cloud correction calculation and broadcast platform match the corresponding corrections according to the terminal location, and then send them to the terminal through the cellular network user plane (internet).
- The terminal device performs high-accuracy positioning based on its own satellite observation data and differential corrections received.
- In this way of broadcasting, the mobile communication network acts only as a data channel; no direct link between differential correction data and single cell.

- The high-precision GNSS differential corrections are broadcast to users by RSUs.

  In this solution, the terminal device does not need to establish a connection with the cloud platform. A RSU can broadcast differential correction directly. Compared to the unicast-based solution described above, it reduces the E2E latency for the positioning acquisition, which can improve accuracy. It further avoids the conflict between terminal device and other users connected to the mobile communication network. As differential correction is broadcast by RSU via PC5 interface, frequent handover between the base stations in the mobility scenario is not needed. The implementation steps are as shown in following figure.

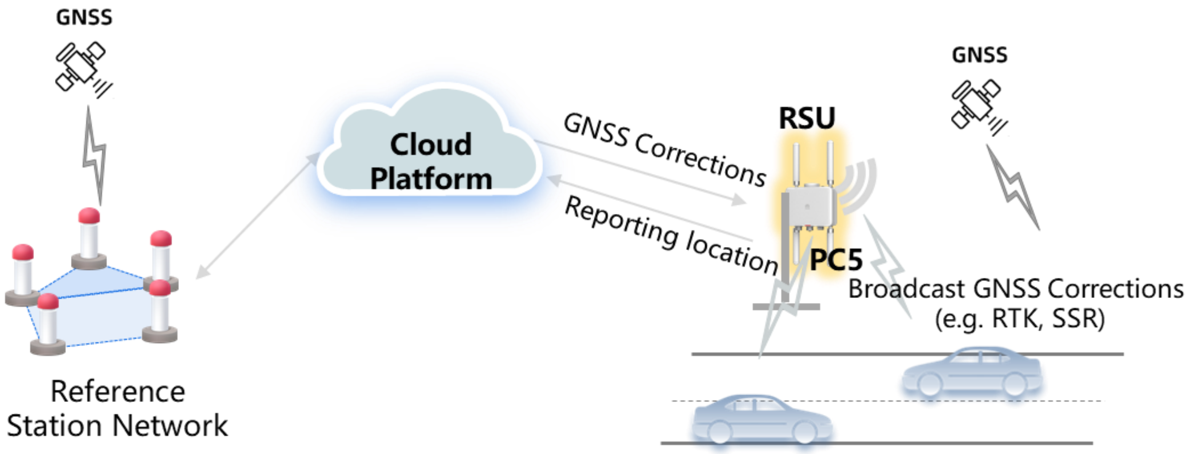


Figure 7.2.1-2: Step of high-precision GNSS differential corrections broadcasting by Road Side Units

- Observation satellite data from the ground reference station and original satellite observation data are transmitted to the cloud correction calculation and broadcast platform.
- After the cloud correction calculation and broadcast platform receive the original satellite observation data, it begins real-time network modelling and calculation, and forms the 'differential correction' per regional grid.
- RSU sends a request for high-precision correction and reports its position obtained by satellite.
- Cloud correction calculation and broadcast platform match the corresponding corrections according to the RSU's location.
- RSU broadcasts the differentials corrections to the terminal device through PC5 interface.
- The terminal device performs high-accuracy positioning based on its own satellite observation data and differential corrections received

As an additional option to the NTRIP protocol, the cloud platform can perform a push mechanism to calculate and update the differential correction of the RSU.

This solution is implemented at RSU-level as an enhanced application function. As the differential correction is acquired and transmitted via data plane, no modification on the current access layer and network layer is required. For instance, the broadcast on PC5 can follow protocols such as 'dedicated short message protocol' (DSMP) or 'wave short message protocol' (WSMP). On the application layer, the terminal devices receive the differential correction information in the same way as they receive the other (e.g. traffic assistant information) broadcast by the RSUs; namely, registration at the application server is needed in advance. The proposed architecture also supports the broadcasting of SSR corrections from the cloud. SSR is further described in Section 7.2.2.

- High-accuracy GNSS differential correction broadcasting through the control plane of cellular network.

  To adapt to different scenarios, high-accuracy GNSS is imported into the control plane of the mobile communication network, which supports the transmission of both unicast and broadcast corrections. Details are mainly based on the steps in the following figure.

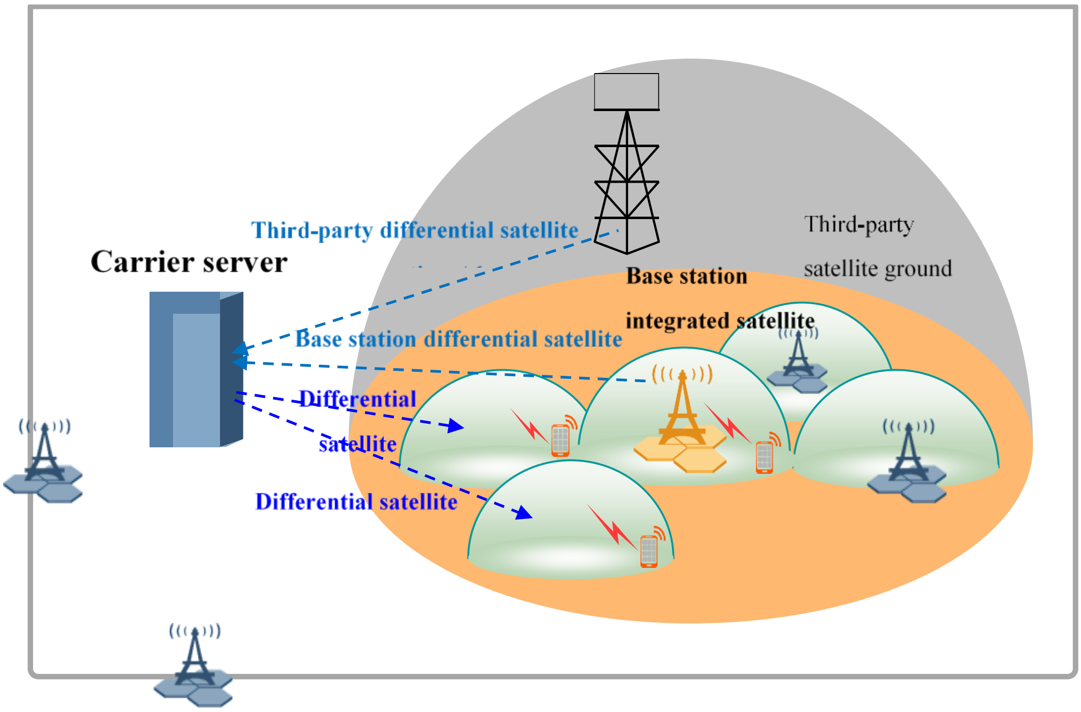


Figure 7.2.1-3: High-accuracy GNSS positioning schemes based on mobile communication network

- The operator's location server can obtain observations from a reference station, which can be third-party or upgraded based on the BS in the cellular network).
- In a cell, the location of the BS can be seen as the user's approximate location. The location server can obtain the BS' location information by deployment or BS report.
- The location server models and generates the correction, based on the BS' location information and measured values from the reference station, and then transmits it to the terminal via unicast or broadcast, depending on different application scenarios.
- After the correction is obtained, the terminal will compute the positioning calculation.

Finally, it should be noted that the RTK technique is a form of 'observation space representation' (OSR), given that the user device positions are computed using corrected 'observations' from a nearby base station or network of stations. The highly dynamic nature of the errors affecting these observations typically requires correction updates at a rate of 1Hz, meaning RTK consumes around 2kbps depending on the number of GNSS signals and constellations supported. The differential technique is less effective over larger distances (e.g. >50km) given that the errors affecting the GNSS observations begin to decorrelate (e.g. atmospheric conditions change over greater distances). It can also be difficult to continue observing and correcting the same satellites as the baseline continues to increase (e.g. for low elevation satellites).

OSR differs from SSR, which is elaborated on in the following section. Rather than correcting the overall observations through a 'lump sum' adjustment, SSR enables the individual 'state' of each error (satellite orbit, satellite clock, code/phase biases, ionosphere, troposphere) to be modelled and sent to the user device at the preferred update rate, thereby reducing bandwidth.

The framework of the standard system for differential correction broadcasting through the control plane of the LTE cellular network is as follows:

- High-accuracy GNSS mainly refers to the information exchanges involving UE, eNB, MME and Enhanced Serving Mobile Location Center (E-SMLC) (location server) in the mobile cellular network.
- When unicast is used, it mainly refers to one-to-one information exchanges between the UE and E-SMLC. The positioning signalling protocol stack between E-SMLC and UE is shown in Figure 7.2.1-4.

- When broadcast is used, the location server transmits data to the BS through an interface protocol LPPa. The BS broadcasts to the terminal through air interface. The positioning signalling protocol stack between E-SMLC and eNB is as shown in Figure 7.2.1-5. The control-plane protocol stack between eNB and the UE is as shown in Figure 7.2.1-6.

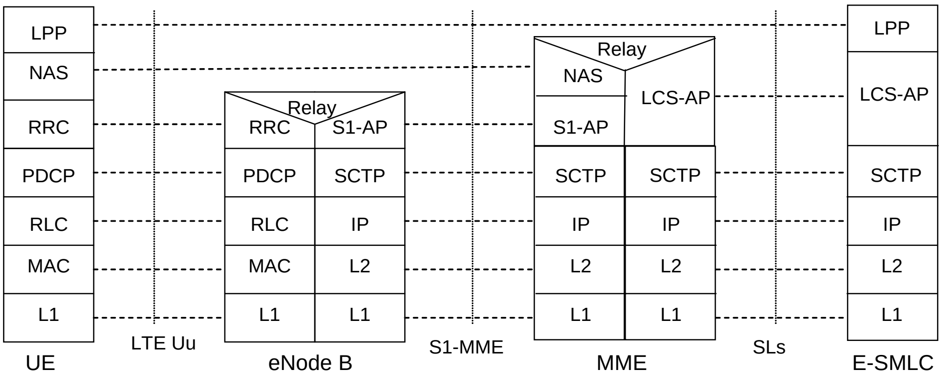


Figure 7.2.1-4 Positioning signalling protocol stack between E-SMLC and UE

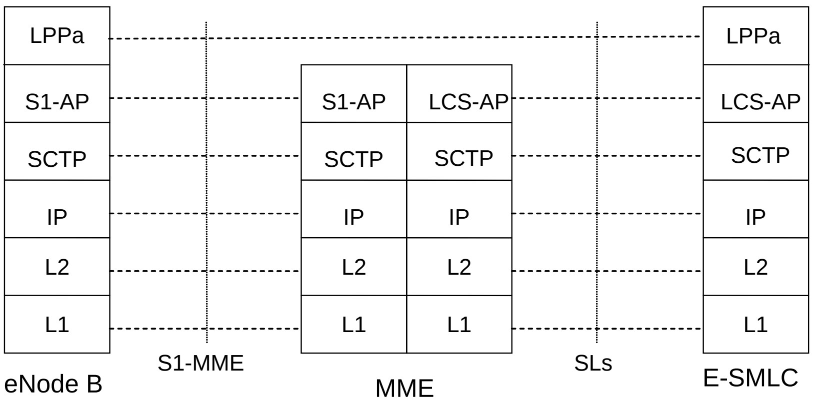


Figure 7.2.1-5 Positioning signalling protocol stack between E-SMLC and eNB

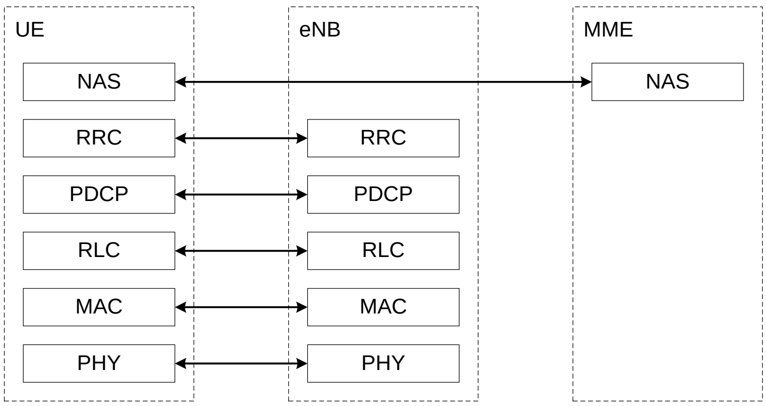


Figure 7.2.1-6 Control-plane protocol stack between eNB and the UE

Based on regulatory considerations, whether unicast or broadcast should be used in the dissemination of high-accuracy GNSS corrections, and how to conduct user audits and usage reports, still need further research and discussion.

3GPP has evaluated positioning improvements for 5G New Radio in TR 38.855 [9]. Metre-scale accuracy requirements emanated from 911-emergency calls. For this, improvements to radio (RAN1) were proposed. For centimetre-scale accuracy, GNSS with RTK correction is promoted. For this it was proposed to include the LTE Positioning Protocol (LPP) solution also in 5G New Radio. This was further analysed in R1-1903022 [10] and R1-1902549 [11] where centimetre accuracy of the solution is confirmed. The LTE solution uses system information blocks (SIB) that are broadcasted by cells and contain the RTK correction information allowing centimetre-accurate positioning. SIB broadcasting does not require (e)MBMS. It is part of the RAN control plane (Broadcast Control Channel) that is received by all UEs.

7.2.2 GNSS location based on SSR services

State-space representation is a modern, high-accuracy (centimetre-level) GNSS positioning technique which has been standardised in 3GPP LPP Release 16 [15, 16, 17]. SSR differs from OSR by enabling the individual ‘state’ of each error component to be modelled and sent at the optimum update rate, leading to bandwidth reductions and other advantages described below. The primary SSR correction messages supported in LPP are the satellite orbit, satellite clock, satellite code and phase biases, and the tropospheric and ionospheric corrections.

Implementation of the SSR corrections enables various positioning modes, in particular the precise-point positioning RTK (PPP-RTK) mode. PPP-RTK extends the global error states, namely satellite orbit, clocks and biases, used in PPP with additional local atmospheric corrections. Figure 7.2.2-1 presents a visual representation of the differences between OSR and SSR including the ability to save bandwidth by decoupling the SSR error states and updating them at their preferred rates, instead of sending a lump sum observation every 1Hz (i.e. using OSR).

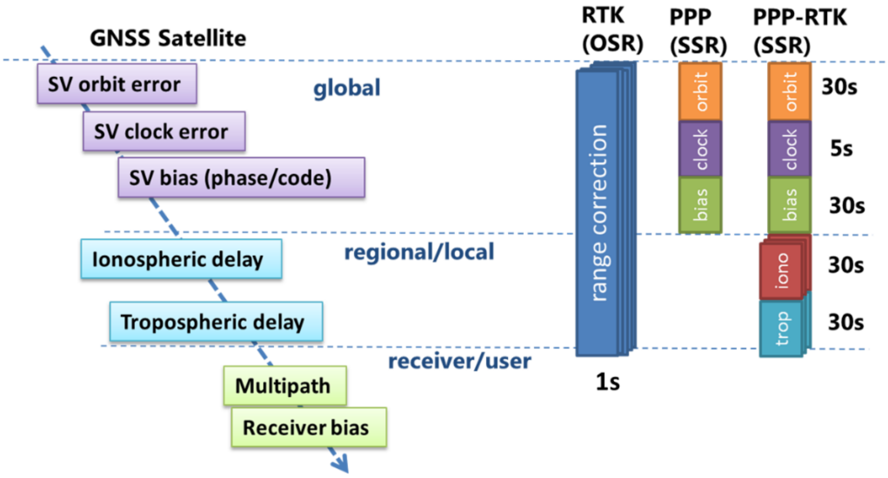


Figure 7.2.2-1 Comparison of SSR and OSR error corrections (adapted from [16])

Importantly, SSR is a true broadcast solution supported within the control plane SIBs introduced in Section 7.2 for 3GPP LPP (Release 16). It enables contiguous coverage by modelling a consistent set of global and local error states which are valid across the entire coverage region rather than tied to specific base stations or local networks. SSR also provides flexibility on the base station spacing and network design, which supports more cost-effective deployments across a large coverage region. Figure 7.2.2-2 presents a simplified diagram of the control plane and user plane architectures for an SSR service interface with the NG-RAN.

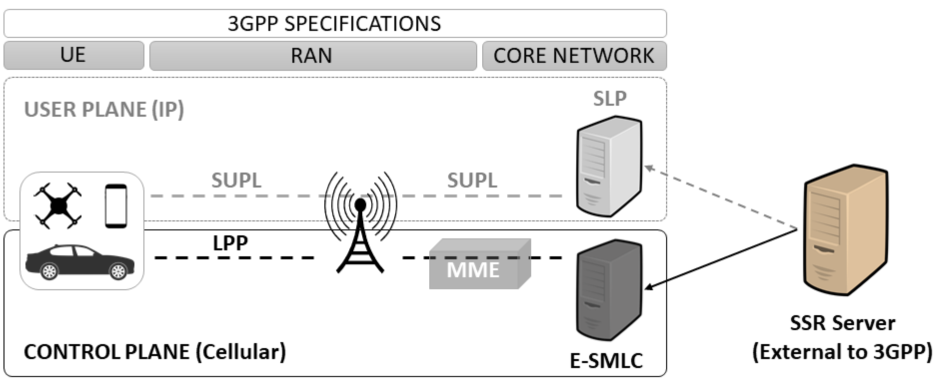


Figure 7.2.2-2 Control plane and user plane positioning architecture in 3GPP, with external SSR interface

SSR accuracies can also be scaled depending on the application requirements and associated resource constraints of the client hardware and software (e.g. only a subset of the messages might be needed for certain applications). The ability to individually model the GNSS error states is also an important capability for appropriately characterising the estimated positioning accuracy in order to meet the integrity requirements introduced in Section 5.1.

The ability to scale to much larger geographic regions and numbers of users via efficient signalling has led to strong demand for SSR among automotive and mobility users, which is reflected by the latest SSR extensions to 3GPP as the industry standard.

7.3 Location service based on sensors and HD map matching

Visual positioning means to obtain visual images through sensors such as a camera or laser Radar (LiDAR), then extract 'consistency information', and estimate the position of the vehicle according to changes in the image sequence information. According to the strategy adopted in positioning, it can be divided into three methods: global positioning based on landmark database and image matching, simultaneous localisation and mapping (SLAM) based on simultaneous localisation and map construction, and a 'visual odometer' based on local motion estimation.

- **Global positioning**: It requires the collection of scene images and establishing a global map or roadside database in advance. When the vehicle needs to be positioned, a current 'pose' image is matched with the roadside database, and the relative position between the current image and the corresponding roadside is estimated. Finally, global positioning information can be obtained.
- **V-SLAM**: SLAM based on the acquired visual information, map construction and localisation of the areas passed by the vehicle as it moves.
- **Visual odometer**: It is a method for incrementally estimating the motion parameters of a mobile robot. The visual odometer method focuses on how to calculate the 'pose' changes of the robot reflected by adjacent images in a sequence, and integrates the results of local motion estimation into the vehicle track.

Compared with a traditional map, the HD map applied to automated driving provides richer semantic information; it not only contains the driveway model, such as the lane line, slope, curvature, heading, lane properties, but also includes a large number of positioning objects. These include the road and various static objects such as the curb, barrier, traffic signs, traffic lights, telephone poles, etc. These elements contain precise location information, through the Light Detection and Ranging LiDAR, camera and millimetre-wave Radar to identify all kinds of static features on the map, and then match these with objects stored in the map file. After the matching process, the precise position and pose of the vehicle itself can be obtained through the relative attitude and position in order to establish self-positioning without GPS, as shown in Figure 7.3-1.

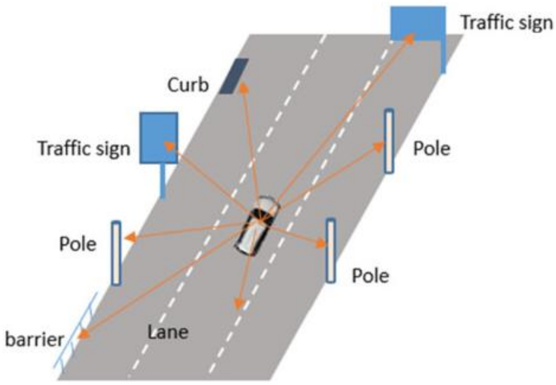


Figure 7.3-1 HD map matching and positioning based on semantic level

The principle of HD map positioning based on the 'semantic level' is to obtain the positioning prediction value by 'inertial recursion' or 'dead reckoning'. Then it positions through map matching and RTK, as well as filter fusion to correct the prediction result, and finally it obtains accurate positioning information. The specific process is shown as in Figure 7.3-2.

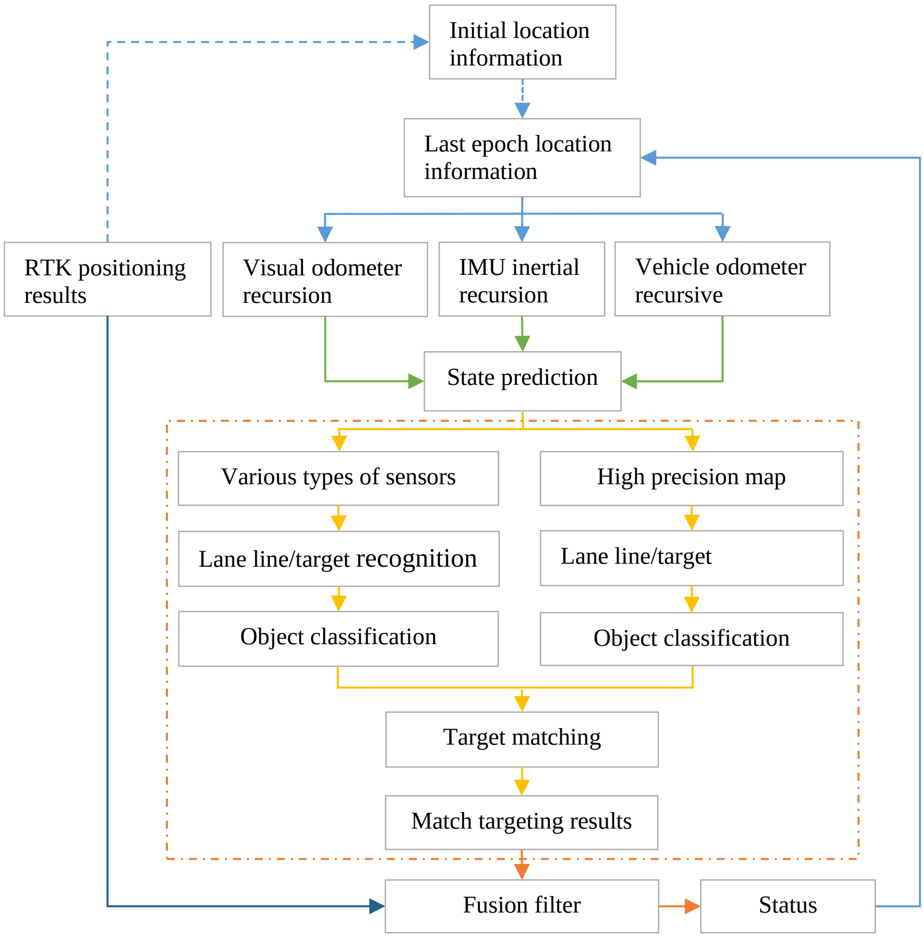


Figure 7.3-2 HD map matching and positioning based on semantic level

- All kinds of sensors (LiDAR, MMW Radar, camera) on the body of the vehicle can synchronise time and space through calibration and timing.
- Use GNSS RTK and inertial navigation to provide initial position, speed and pose.
- At the ‘last epoch’ stage, the next epoch is predicted by means of inertial navigation/vehicle odometer/visual odometer (normally, the inertial navigation output time interval is one epoch).
- Depending on the current predicted position, the semantic information generated for the HD map by the car’s external sensors is extracted, including the object information of lane line, curb, barrier, traffic sign, traffic light, telegraph pole, etc., and classified by the target category.
- Each sensor combined with the vehicle prediction state, identifies the lane line/target and classify the objects.
- Objects are matched according to their classification.
- After matching takes place, depending on the object position/pose information stored in the HD map and combined with the sensor ranging/attitude measurement results, the vehicle position and attitude information is calculated in reverse to obtain the matching positioning result.
- RTK positioning/matching result and vehicle prediction state will be fused and filtered to obtain the final positioning and update of the vehicle’s state.

7.4 Location services based on cellular network

Location services or LCS generally refers to a kind of value-added service which can obtain the location information (latitude and longitude, altitude information, etc.) of mobile users through the telecommunication operator network (such as GSM/UMTS/CDMA/LTE/NR and other wireless network systems), and combines it with an electronic map or other user services.

The logical architecture of LCS based on a cellular network is shown in Figure 7.4-1. Generally, the basic positioning process is initiated by the 'LCS client' sending location information to the server. And the 'LCS server' executes or takes a measurement of the positioning target by configuring the wireless access network node, or it obtains the location-related information from the positioning target by other methods. Finally, the location information is calculated and matched with the coordinates.

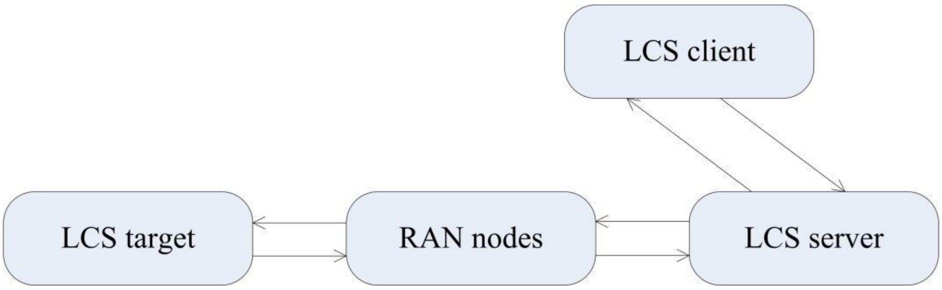


Figure 7.4-1 Basic process of cellular network positioning

Illustrated thanks to the E-UTRAN positioning system, its architecture is shown in Figure 7.4-2. E-SMLC can be regarded as a location server in the control layer, which can be a logical unit or an entity unit. The mobility management entity (MME) accepts requests from other entities or initiate positioning requests by itself; the location measurement unit (LMU) might be used to exchange measurement information, especially uplink location information with the E-SMLC, and often combined with the eNB; service location protocol (SLP) is an entity carrying the secure user plane location (SUPL) protocol, which can usually be considered as a location server on the user plane; SUPL location information is processed and transmitted on the user plane through the SUPL protocol; SET refers to the location target of the user plane.

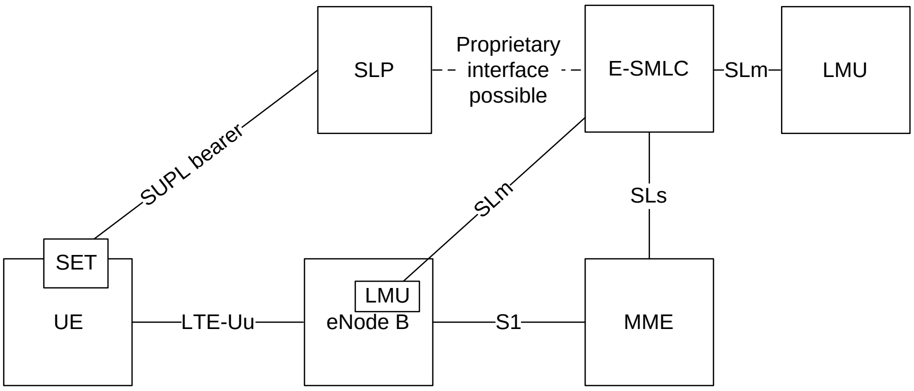


Figure 7.4-2 E-UTRAN positioning architecture (Source: 3GPP TS 36.305)

On the communication protocol, signalling between UE and the E-SMLC entity is communicated by the LPP; between eNB and the E-SMLC entity it is communicated by the LTE Positioning Protocol A (LPPa).

As shown in Figure 7.4-2, the E-UTRAN UE positioning process mainly refers to five functional entities: UE, eNode B, MME, E-SMLC, and the 'Evolved packet core network location service entity' (EPC LCS). Details are shown in Figure 7.4-3:

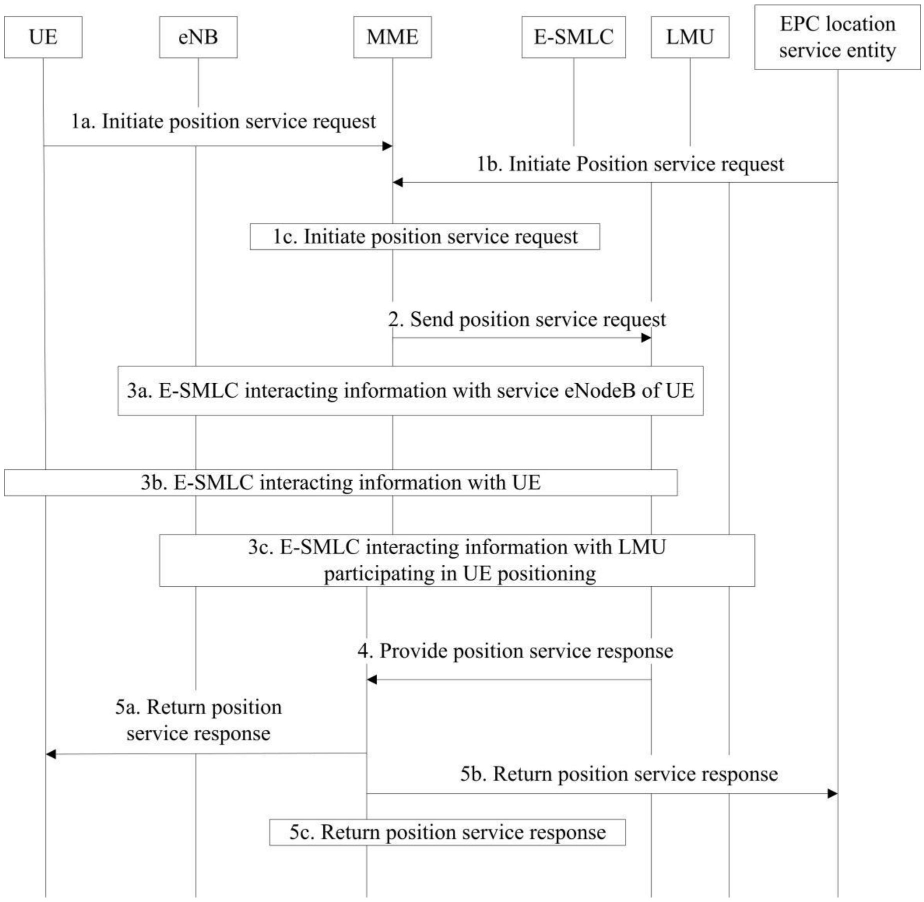


Figure 7.4-3 E-UTRAN to UE positioning process

- Step 1a: The UE requests a certain location service (positioning or providing auxiliary data) from the MME through NAS signalling.
- Step 1b: Some entities in the core network (such as service request based on location information) send a location request from the target UE to serving MME.
- Step 1c: The Serving MME decides to initiate a location service request from the target UE (such as obtaining the location of the emergency call).
- Step 2: The MME sends a location service request to the E-SMLC.
- Step 3a: The E-SMLC interacts with the UE's serving eNB through LPPa protocol to obtain positioning measure or assistant data.
- Step 3b: Follow or omit step 3a, the UE could interact with the downlink positioning E-SMLC through the LPP protocol to obtain the location estimation or positioning measurement, or to receive positioning assistance data.
- Step 3c: For the uplink positioning (such as UTDOA), in addition to performing step 3a, the E-SMLC needs to interact with multiple LMUs used in the UE positioning to obtain positioning observations.
- Step 4: E-SMLC provides the MME with a location service response, including all of the desired results (such as an indication of success/failure or location estimate of the UE).
- Step 5a: If step 1a is performed, the MME returns a location service response to the UE (e.g. location estimate of the UE).
- Step 5b: If step 1b is performed, the MME returns a location service response to the EPC entity.
- Step 5c: If step 1c is performed, the MME uses the location service of step 4 to respond to the location service triggered by step 1c.

Due to signal bandwidth, synchronisation and network deployment, earlier cellular positioning systems could only manage accuracy in the tens of metres. With the arrival of 5G, large bandwidth, multi-antenna and high-accuracy synchronisation technology, these supports will greatly improve the positioning accuracy, and make up for the shortage of satellites and positioning, especially in indoor settings and tunnels.

7.5 Sidelink positioning

7.5.1 Positioning service based on sidelink

Conventional RAT-dependent positioning techniques such as OTDoA and UTDoA are based on Uu-link for PRS transmission and the relevant positioning measurement. Sidelink positioning is a technique that uses a sidelink for sending S-PRS and taking measurements for terminal positioning. The measurement can include the time of arrival (ToA), angle of arrival/angle of departure (AoA/AoD), reference signal time difference (RSTD), etc., measured by a terminal for ranging and positioning. Similarly, such a sidelink could be promisingly exploited for C-V2X positioning by providing high reliability, accuracy and availability. In this service, sidelink positioning will be exploited for the S-PRS transmission and positioning assistance data, and the measurement can be transmitted on either sidelink or Uu link.

Sidelink positioning can provide the absolute position or relative position of a terminal, as follows:

- **Absolute position**: The longitude and latitude coordinates of a terminal (e.g. vehicle or VRU) is calculated. The coordinates of an anchor such as a RSU are necessary.
- **Relative position**: The relative position information such as distance and angle between UEs is calculated. The positioning operation can be performed among moving UEs. It can be useful in some applications such as collision warning. It can also be useful to improve the accuracy of absolute positioning for a UE acquired by other means (e.g. in cooperative positioning).

  NOTE: Absolute positions are used to identify the coordinates of a user device in a global (earth-fixed) reference frame, such as the International Terrestrial Reference Frame (ITRF). For example, GNSS is an absolute positioning system. Aligning the location of supporting infrastructure (e.g. RSU, base stations) to an absolute reference frame achieves the highest positioning accuracy and consistency for the user. For example, many applications require positions to be referenced to the underlying map data, which should be matched to the same absolute reference frame as the positioning infrastructure. The concept of absolute positioning is also discussed in Section 7.1.

Next is the description of the sidelink positioning mode. The sidelink positioning is categorised into sidelink-assisted positioning and sidelink-based positioning modes according to whether the position of a terminal is calculated by a terminal or the position of a terminal is calculated by a network (e.g. LCS). Here, it is noted that the aforementioned basic sidelink interface roles are identical for both modes.

- **Sidelink-assisted positioning mode**:

  In the sidelink-assisted mode, the position of a terminal is calculated by LCS. After calculating the position of a terminal, LCS can feed the position information back to the terminal if needed. At this time, the measurements gathered at the terminals are delivered to LCS via Uu-link (NR/LTE). From the aforementioned, this mode could be regarded as a kind of UE-assisted tool where the positioning calculation is completed on the network side by collecting all the information from both the roadside and terminal side [12]. Figure 7.5.1-1 shows an example to explain the basic concept of sidelink-assisted positioning mode, where three RSUs, gNB/LCS and the vehicle are considered for an absolute positioning. An example procedure can be described as follows:

  - The positioning assistance data needed for positioning set-up/operation can be provided to the vehicle and RSUs via Uu interface from gNB/LCS.

    It is assumed that gNB/LCS knows the absolute position information about RSUs.

  - Each RSU transmits S-PRS along with RSU-ID over sidelink and a vehicle performs the measurement procedure from the received S-PRSs.
  - The vehicle delivers the measurements along with the RSU-ID to the gNB/LCS.
  - Finally, the LCS calculates the position of the vehicle from the measurement received and fixed position of RSUs.

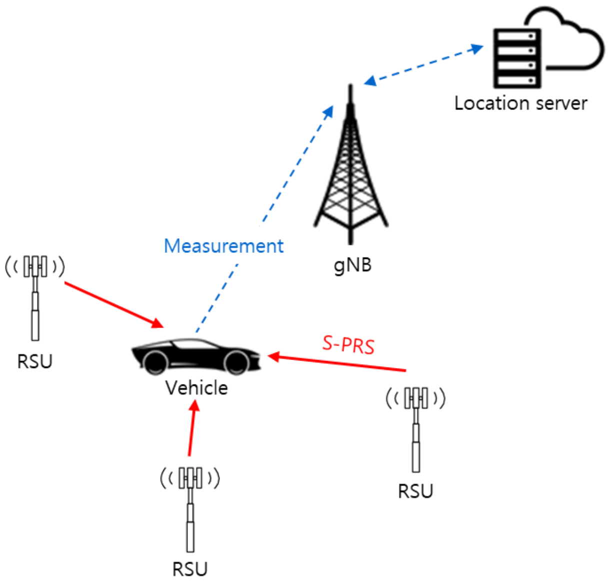


Figure 7.5.1-1 An example of sidelink-assisted positioning mode

- **Sidelink-based positioning mode**:

  In contrast to the sidelink-assisted positioning mode, the position of a terminal in the sidelink-based positioning mode is calculated by the terminal. Hence, the sidelink-based positioning mode could be regarded as a kind of UE-based positioning where the calculation is completed at the terminal side [12]. Figure 7.5.1-2 shows an example of the basic concept of sidelink-based positioning mode where, similar with Figure 1, three RSUs and a vehicle are considered for absolute positioning. An example procedure for this can be described as follows:

  - The positioning assistance data needed for positioning set-up/operation can be provided to the vehicle and RSUs via Uu-link from the gNB/LCS. Alternatively, such a S-PRS configuration could be determined by RSUs regardless of their connection with a network.
  - Each RSU transmits S-PRS along with its absolute position information over sidelink and the vehicle performs a measurement procedure from the received S-PRSs.
  - Finally, the vehicle calculates its position by using the measurements and the absolute positions of RSUs.

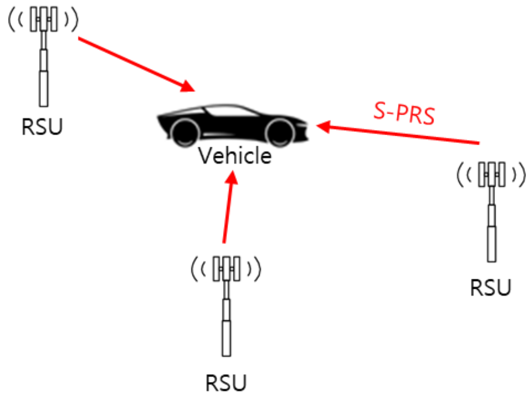


Figure 7.5.1-2 An example of sidelink-based absolute positioning

Figure 7.5.1-3 shows another example of the sidelink-based positioning mode to obtain the relative position, where two vehicles ('ego-vehicle' and neighbouring vehicle) and a VRU are considered:

- The assistance data for positioning set-up/operation can be provided to vehicles/VRUs from the gNB/LCS or can be determined by the vehicles/VRUs participating in the positioning procedure.

- Considering RTT-based positioning, the ego-vehicle transmits an S-PRS request and receives an S-PRS response from a neighbouring vehicle/VRU. In addition, during the S-PRS exchange, the ego-vehicle obtains the measurements of relative distance and AoA needed to ascertain the relative positioning.
- Finally, the ego-vehicle calculates its position relative to the neighbouring vehicle/VRU.

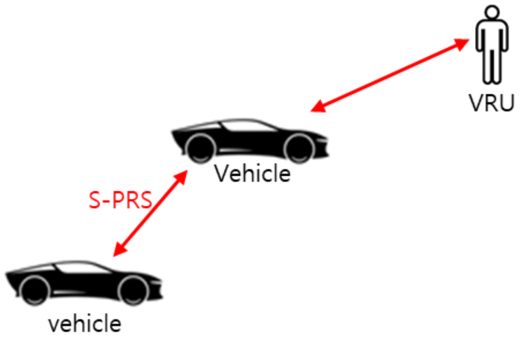


Figure 7.5.1-3 An example of sidelink-based relative positioning

7.5.2 Sidelink positioning leveraging vehicle dynamics

In C-V2X HAP positioning, the transmission of positioning reference signals over the sidelink (S-PRS) is exploited; the positioning assistance data and the measurement can be transmitted on either sidelink or Uu link. The measurement can include the ToA, AoA/AoD, and RSTD. Sidelink positioning can be considered as a solution to improve the availability of positioning, for example, when Uu positioning is not available (e.g. terminals are out of coverage), and when GNSS signals are not available (e.g. in places like tunnels, heavy urban scenarios, etc.). In C-V2X communications, sidelink positioning can benefit from leveraging the unique dynamics information (e.g. vehicle mobility with potentially significant dynamics of a terminal with respect to an anchor node, like RSUs or other vehicles, over a short duration of time); and thus it is possible to achieve accurate positioning using a limited number of anchors. Note that, S-PRS mentioned here is the positioning reference signal transmitted over sidelink. It may be different from PRS specified in Uu positioning in 3GPP.

Sidelink positioning can provide the absolute position or relative position of a terminal as follows:

- **Absolute position**: The longitude and latitude coordinates of a terminal (e.g. vehicle or VRU, vulnerable road users) is calculated. An anchor with known location, e.g. an RSU or another vehicle, is necessary for sidelink absolute positioning.
- **Relative position**: The relative position such as distance and angle between UEs is calculated. This is also commonly known as 'sidelink ranging'. Ranging can be performed among moving or stationary UEs, which can be useful in applications such as V2V collision warning. A sidelink ranging operation can be performed between a vehicle and a VRU as well, in which case the relative position can be used to reduce the false alarms in the VRU warning system.

The following are descriptions of how to leverage the C-V2X-specific dynamics and additional information (e.g. terminal mobility, terminal on-board sensors for ego-velocity measurements, terminal on-board ranging sensors etc.) to improve or enable accurate sidelink positioning with a limited set of anchors in the system.

○ **Leveraging vehicle on-board sensors and mobility to improve or enable accurate sidelink positioning.**

In the C-V2X scenario, an advantage for positioning implementation is that there may be significant mobility between the anchor and the terminal (e.g. vehicle driving by an RSU, a stationary vehicle trying to position with respect to an anchor vehicle that is driving past, etc.). Furthermore, on-board sensors at the terminal (on the vehicle) provide accurate information about the vehicle's mobility (including velocity, yaw/pitch/roll, acceleration, etc.) such that it offers a very accurate measure of 'terminal displacement' over time. The relative 'mobility' between the anchor and the terminal, and the displacement calculations at the terminal make sidelink positioning using multiple measurements possible. In other words, the multiple measurements over a given timeframe is analogous to positioning using multiple non-collocated entities formed virtually using accurate information of the displacements over time (as depicted in Figure 7.5.2-1). Hence even a single anchor can enable absolute positioning for the terminal. This can offer multiple benefits:

a) Absolute positioning with a reduced number of anchors, even with a single anchor. In turn, this alleviates the need for dense deployments of anchors (e.g. RSUs).

b) Accurate absolute or relative positioning with loose synchronisation requirements (e.g. sub-ns accuracy in synchronisation among the anchors/RSUs is not needed). The multiple time samples provide additional measurements that help to estimate the synchronisation errors. At the terminal (e.g. pedestrian UE) this may alleviate tight Tx-Rx group delay calibration requirements (to be within sub-ns).

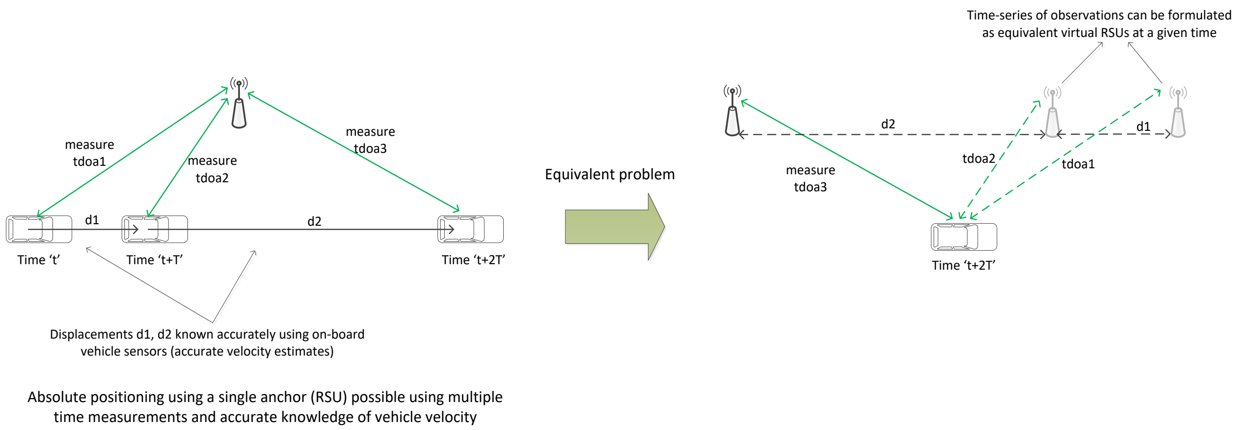


Figure 7.5.2-1 Absolute positioning using a single anchor is possible by leveraging vehicle on-board sensors and mobility*

* The multiple time measurements can be formulated as an 'equivalent problem' with multiple virtual anchors/TRPs providing accurate 'displacement' of the terminal (over a time duration) using on-board sensors.

An example for leveraging vehicle mobility and accurate velocity for absolute positioning of a terminal using a single anchor (e.g. RSU) is shown in Figure 7.5.2-2.

1. The positioning assistance data for positioning set-up/operation can be provided by the RSU (anchor) and the ego-vehicle (terminal).
2. Considering round trip time (RTT)-based ranging, RSU and ego-vehicle send the S-PRS transmissions and measure the TDoA/AoA from the other entity. RSU transmits the measured TDoA/AoA based on the ego-vehicle's S-PRS to the ego-vehicle. It is noted that depending on the implementation of positioning and antenna capability, the AoA measurement may be an accurate AoA or coarse AoA.
3. Ego-vehicle estimates its absolute position using the relative distance and AoA measured using multiple time samples by utilising the accurate information about the velocity of the vehicle (displacement over the time instants) as obtained from its on-board sensors. It is noted that accuracy in obtaining the absolute positioning with one anchor (or reduced set of anchors) depends on the geometry and relative motion of the ego-vehicle with respect to the anchor.

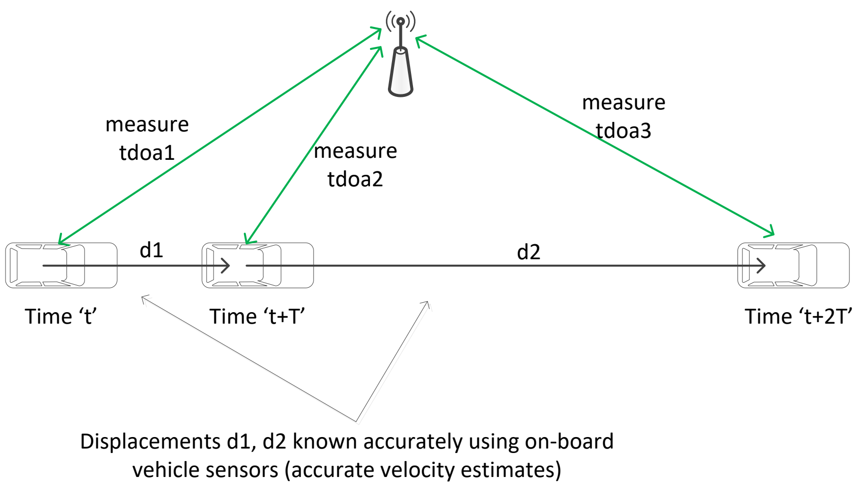


Figure 7.5.2-2 An example of absolute positioning using sidelink and a single anchor by leveraging vehicle on-board sensors and vehicle mobility

An example for leveraging vehicle mobility and accurate velocity for absolute positioning for a non-mobile ego-vehicle and VRU (with low to no mobility) is shown in Figure 7.5.2-3.

1. The assistance data for positioning set-up/operation can be provided by the anchor-vehicle to the ego-vehicle and VRU(s). Two VRUs are depicted: VRU1 crossing the road and VRU2 walking on the sidewalk. The positioning assistance data in this scenario include the absolute position of the anchor-vehicle at each time instant.
2. Considering RTT-based ranging for the ego-vehicle and VRU1, they send the S-PRS transmissions and measure the TDoA/AoA from the other entity. All entities may share the TDoA/AoA measured from the other entities.
3. The non-mobile ego-vehicle can estimate its absolute position using the relative distance and AoAs measured from the anchor-vehicle over multiple time instants by utilising the fact that the anchor-vehicle is moving relative to the ego-vehicle.
4. VRU1 can estimate its absolute position using the relative distance and AoAs measured from the anchor-vehicle over multiple time instants. It is also possible to provide the TDoA/AoA measurements and additional pedestrian sensor information (like speed) to the anchor-vehicle, the anchor-vehicle may track the pedestrian based on the measurements and information.
5. VRU2 can estimate its absolute position using the relative distance and AoAs measured from the anchor-vehicle over multiple time instants. As non-RTT based, modelling of clock bias and drifts will be needed.

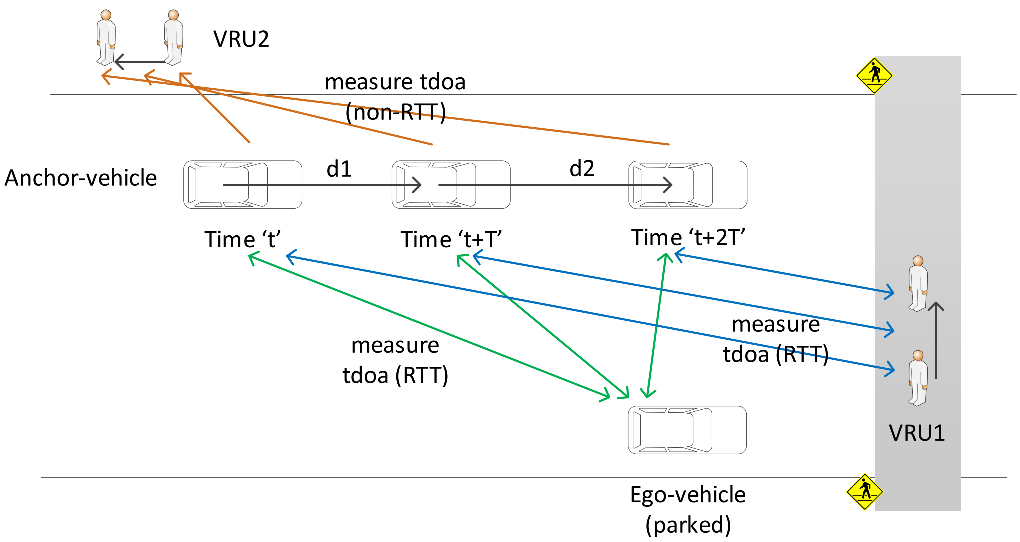


Figure 7.5.2-3 An example of absolute positioning using sidelink and a single anchor for (i) non-mobile ego-vehicle using the relative mobility to the anchor-vehicle, (ii) VRUs using either RTT/non-RTT-based positioning

In the above example, it can be noted that for VRU identification and warning systems, the estimation of the absolute positioning of the VRU can actually be performed at the anchor-vehicle. The anchor vehicle may utilise its other on-board sensors (ranging sensors, camera/LiDAR/Radar-based object detection, etc.) for improving the positioning accuracy. Sidelink positioning provides an important input to enable accurate VRU identification (i.e. which pedestrian is vulnerable vs. which pedestrian is not) such that the false alarms alerting a pedestrian that is not on a collision course are reduced. Utilising the anchor-vehicle's sensor and mobility enables absolute sidelink positioning, which helps to reduce these false alarms.

Although the above positioning examples are elaborated based on S-PRS transmission on sidelink, it is noted that some of the positioning approaches that leverage vehicle dynamics can also be applied to Uu positioning; for example, the PRS can be transmitted by base stations in downlink, and/or the PRS can be transmitted by vehicle UEs in uplink.

7.5.3 Spectrum requirement for sidelink positioning

In sidelink positioning, the accuracy of positioning depends on the signal bandwidth of the S-PRS transmitted on sidelink. In multipath fading channel, the impulse response for each path is a *sinc* (sine cardinal) function, and the larger the bandwidth, the 'narrower' the *sinc* function. Therefore, it is important that the *sinc* is 'narrower' so that the time of arrival (ToA) of the first path is distinguishable in S-PRS measurement (Figure 7.5.3-1). In other words, the larger the positioning signal bandwidth, the higher the positioning accuracy.

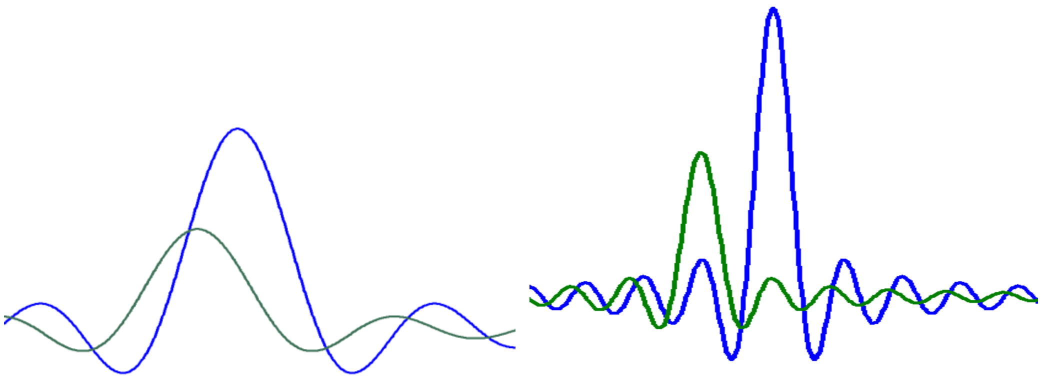


Figure 7.5.3-1 Channel impulse response of smaller bandwidth signal (left) and larger bandwidth signal (right)

In 3GPP SA1 specification 22.186, the requirements to V2X positioning accuracy have been specified. Specifically [24]:

- The 3GPP system shall support relative lateral position accuracy of 0.1m between UEs supporting V2X application.
- The 3GPP system shall support relative longitudinal position accuracy of less than 0.5m for UEs supporting V2X application for platooning in proximity.

For these V2X positioning applications, wide-band positioning reference signal transmission is fundamental to achieve the accuracy. It is noted that in 3GPP NR positioning study aiming to understand the relationship between bandwidth and achievable accuracy performance, multiple evaluation sources indicate that to achieve sub-metre-level accuracy with a probability of 50%, positioning signal transmission with at least 100 MHz bandwidth is needed in outdoor scenarios [25].

For sidelink positioning signal transmission, various spectrum options can be considered. For example, ITS band, licensed band, and unlicensed band. It is noted that the S-PRS transmission and the positioning assistance data and measurement transmission may take place in the same band or different bands depending on the operation choice. For example, transmission of the positioning assistance data and measurements can be transmitted over ITS spectrum, coupled with S-PRS transmission on non-ITS (licensed or unlicensed) spectrum.

The following bullets review potential considerations for the bands for sidelink positioning.

- **ITS band:**

  The spectrum band 5850-5925 MHz has been allocated for ITS basic safety services. As the band is dedicated for the use of V2X service, it provides the benefit of the spectrum availability. However, one problem for sidelink S-PRS transmission in ITS spectrum is that the bandwidth may be limited. For example, in the US, there may be only 20MHz ITS spectrum available for CV2X deployment. Unless the whole 70MHz bandwidth is used for positioning purpose, the accuracy obtained by using the ITS band is limited. Therefore, it may be difficult to achieve the desired sub-metre-level accuracy if sidelink S-PRS is transmitted in ITS spectrum. However, depending on the use cases, the ITS band may be applied to the positioning services with somewhat relaxed accuracy requirements. The positioning technique using this band can be combined with other techniques based on the sensor or the camera for positioning accuracy improvement.

If a positioning service is provided in ITS dedicated spectrum, it is desirable for both sidelink communication and positioning to share the same ITS band. Considering that the bandwidth of ITS spectrum is limited, any band fragmentation by introducing a sidelink positioning should be avoided in order to better utilise the ITS spectrum.

It is worth mentioning that a much wider bandwidth is also available for ITS services. Especially in Europe, more than 1GHz spectrum bandwidth on 60GHz band has been considered for the dedicated spectrum for V2X. Such a wide bandwidth should provide a significant benefit in terms of the positioning accuracy and availability.

- **Licensed band:**

  3GPP NR systems provide flexible numerology in spectrum bandwidth, compared to LTE system. Using licensed band for S-PRS transmission is feasible when C-V2X communication shares spectrum with the cellular network. In this case, network nodes (e.g. base stations) may configure S-PRS transmission on sidelink. For example, up to 400MHz of bandwidth can be supported by an NR network; if S-PRS for V2X positioning can be transmitted on NR-licensed spectrum, the bandwidth would be quite sufficient for high-accuracy (less than 0.5m) outputs. Note that the actual positioning accuracy is determined by the bandwidth allocated to the positioning services, and it depends on need/demand in commercial use. It is also noted that S-PRS transmission on licensed band may not be guaranteed, depending on C-V2X deployment. For example, the S-PRS transmission would not be available when C-V2X devices do not have Uu capability, i.e. C-V2X is deployed out of network coverage.

- **Unlicensed band:**

  One motivation for using unlicensed band is to accommodate S-PRS transmission over wide-band spectrum. For example, U-NII-3 has 125MHz bandwidth available (5.725- 5.85GHz). It is noted that in this scenario, the unlicensed spectrum may be used only for S-PRS transmission; assistance information related to the S-PRS transmission in unlicensed spectrum and information related to measurements can still be transmitted over licensed spectrum or ITS spectrum depending on C-V2X deployment. In this scenario, the use of two different bands needs to be taken into account in hardware implementation. For S-PRS transmission in unlicensed spectrum, it is noted that use of the spectrum is subject to regulatory requirements depending the region, which may cause other problems in sidelink positioning, e.g. excessive delay or potential interference if the band is shared with other technologies. All these issues need to be technically solved; however the availability of the spectrum is one of the most important merits for its positioning use.

7.6 Other schemes for improving positioning accuracy on network side

7.6.1 Antenna/RSU distribution/deployment technique

In general sense of this technique, the locations of antennas are properly determined and exploited for the purpose of positioning enhancement. Locating antennas can be implemented on both sides; it can be the form of antenna distribution on the vehicle side (a.k.a. DAS) and it can appear as an RSU deployment on the infrastructure side.

From [13]-[14], it is noted that the distribute antenna system (DAS) on a terminal is an important solution to increase communication capability such as an antenna coverage. For example, when considering two antenna panels for DAS, each can be installed at the front bumper and at the rear bumper (or at the front or rear of the rooftop) respectively, as shown in Figure 7.6.1-1.

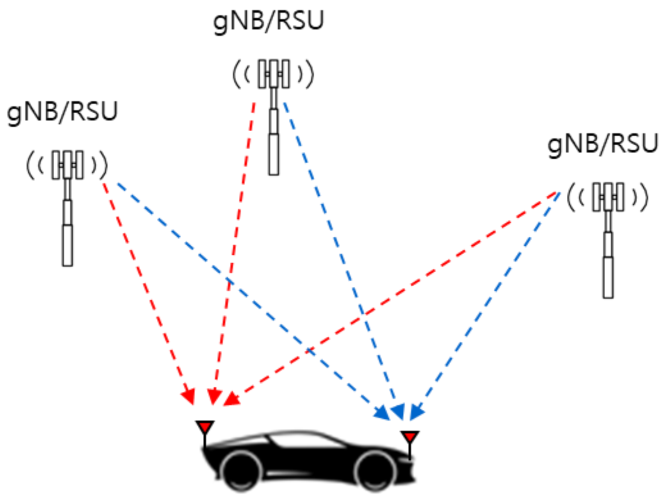


Figure 7.6.1-1 Example of positioning with DAS

The aim of the antenna distribution technique is to leverage DAS and improve the positioning performance such as accuracy, reliability and availability. This can be achieved by properly combining the measurements from distributed antennas, as described below.

For a vehicle, this is usually represented by its reference point (e.g. the centre of the vehicle) as its location, which is signalled by a CAM message, for instance. After estimating each antenna location using, for example, the TDOA method, the antenna location can be converted to the vehicle location using the DAS geometry.

Assume that multiple distributed antennas are mounted on a vehicle, as shown in Figure 7.6.1-2. The number and the location of the distributed antennas may depends on the V2X performance/coverage requirements and the shape/design of a vehicle. Let $(\boldsymbol{x_i}, \boldsymbol{y_i})$, $\boldsymbol{d_i}$, and $\boldsymbol{\theta_i}$ be the location, the distance from the reference point, and the angle between the vehicle direction and the coordinate direction of the *i*-th antenna. Then the reference point $(\boldsymbol{x_{Ri}}, \boldsymbol{y_{Ri}})$ converted from the *i*-th antenna location $(\boldsymbol{x_i}, \boldsymbol{y_i})$ is obtained by the following equation.

$$(\boldsymbol{x_{Ri}}, \boldsymbol{y_{Ri}}) = (\boldsymbol{x_i}, \boldsymbol{y_i}) - (\boldsymbol{d_i}\cos(\boldsymbol{\theta_i}), \boldsymbol{d_i}\sin(\boldsymbol{\theta_i})) \quad (1)$$

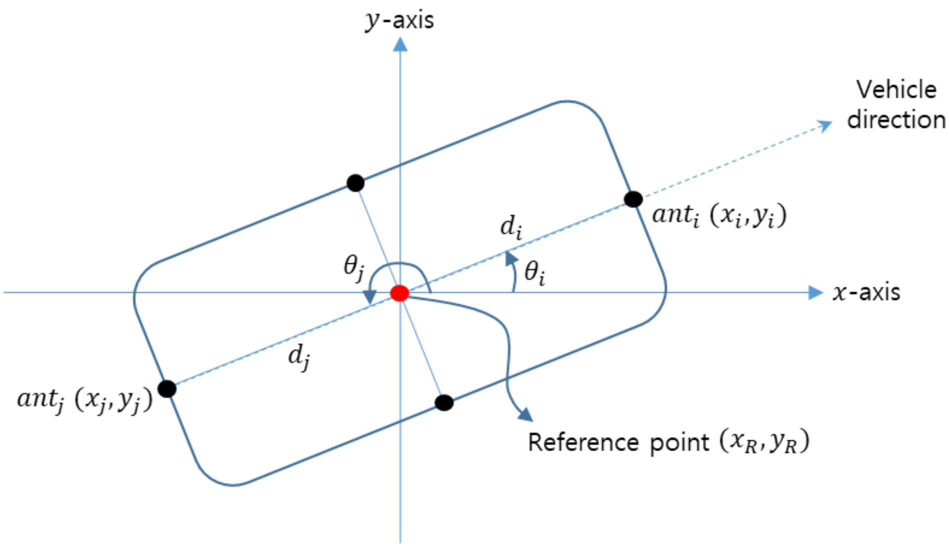


Figure 7.6.1-2 Example of DAS and a reference point of a vehicle

As explained above, the vehicle location can be independently estimated from each antenna position of DAS. To improve the accuracy of vehicle positioning, those vehicle locations, independently estimated from each antenna, can be combined together. One of the solutions may be to apply a weighting factor based on the reliability of each estimate, which can be decided according to the received signal quality or the number of RSUs/gNBs used for each antenna positioning. The final reference point location $(\boldsymbol{x_R}, \boldsymbol{y_R})$, that is the vehicle location, can be determined as follows.

$$(\boldsymbol{x_R}, \boldsymbol{y_R}) = \sum \boldsymbol{\beta_{Ri}} \cdot (\boldsymbol{x_{Ri}}, \boldsymbol{y_{Ri}}), \tag{2}$$

where $\mathbf{0} \leq \boldsymbol{\beta_{Ri}} \leq \mathbf{1}$ is a weighting factor for the estimated reference point $(\boldsymbol{x_{Ri}}, \boldsymbol{y_{Ri}})$ and $\sum \boldsymbol{\beta_{Ri}} = \mathbf{1}$ needs to be satisfied.

As an another example, when a TDoA-based positioning such as OTDoA is supported from gNBs/RSUs, the accuracy and reliability of positioning can be degraded due to imperfect synchronisation among gNRs/RSUs. The effect of the timing error can be mitigated by subtracting two TDoA measurements from two distributed antennas, where two TDoA measurements are obtained for the same pair of gNBs/RSUs.

Now assume there are multiple (at least three) RSUs around a vehicle, on which multiple DAS antennas are mounted. The timing error $\mathbf{te}_{i,j}$ between *i*-th RSU and *j*-th RSU can be cancelled out from the two RSTDs estimated at *m*-th antenna and *n*-th antenna of DAS, with the following equations.

$$\boldsymbol{RSTD_{i,j}^m} = \boldsymbol{\tau_{RSU_i}^m} - \boldsymbol{\tau_{RSU_j}^m} + \boldsymbol{te_{i,j}} + \boldsymbol{e_m}$$

$$\boldsymbol{RSTD_{i,j}^n} = \boldsymbol{\tau_{RSU_i}^n} - \boldsymbol{\tau_{RSU_j}^n} + \boldsymbol{te_{i,j+}e_n}$$

$$\boldsymbol{RSTD_{i,j}^m} - \boldsymbol{RSTD_{i,j}^n} = \left(\boldsymbol{\tau_{RSU_i}^m} - \boldsymbol{\tau_{RSU_j}^m}\right) - \left(\boldsymbol{\tau_{RSU_i}^n} - \boldsymbol{\tau_{RSU_j}^n}\right) + \boldsymbol{e}, \tag{3}$$

where $\boldsymbol{e_m}$ and $\boldsymbol{e_n}$ are the estimation error at *m*-th and *n*-th antenna respectively, and $\mathbf{e} = \boldsymbol{e_m} - \boldsymbol{e_n}$ is the resultant estimation error. If more than two pf the above equations are obtained through a different pair of RSUs, the antenna location, and thereby the vehicle location, can be estimated without degradation caused by the network timing synchronisation error. It is an important benefit of DAS in that it does not require any network synchronisation condition for high-accuracy positioning.

In another instance, the antenna distribution technique enables the position to be acquired even with a reduced number of gNB/RSUs. The RSTDs measured at each antenna can be combined with the absolute position information from the RSUs/gNBs in order to calculate the absolute position of a terminal, though there are less than three RSUs/gNBs required by the conventional OTDoA method. In Figure 7.6.1-3, utilising the known distance between two antennas enables a vehicle to perform position calculation even with two gNBs/RSUs.

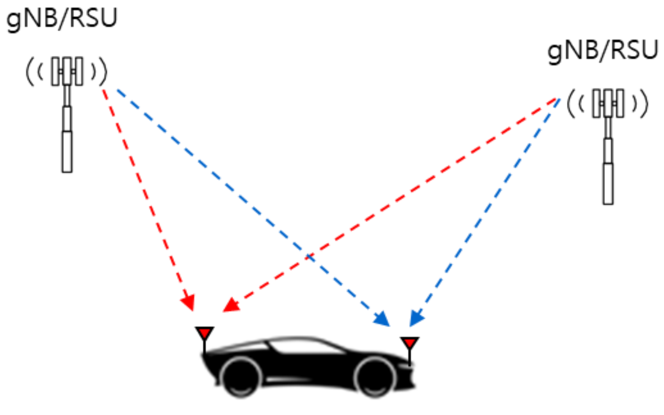


Figure 7.6.1-3 Example of positioning using DAS with two gNBs/RSUs

Assume that a vehicle uses a DAS with multiple antennas, as described in Figure 7.6.1-2, and there is no network timing error for simplicity. Then, RSTD in equation (3) can be expressed by the coordinates of RSUs and a vehicle, as below.

$$\boldsymbol{RSTD_{i,j}^m} = \sqrt{\left(\boldsymbol{x_{RSU_i}} - \boldsymbol{x_m}\right)^2 + \left(\boldsymbol{y_{RSU_i}} - \boldsymbol{y_m}\right)^2}/\boldsymbol{c} - \sqrt{\left(\boldsymbol{x_{RSU_j}} - \boldsymbol{x_m}\right)^2 + \left(\boldsymbol{y_{RSU_j}} - \boldsymbol{y_m}\right)^2}/\boldsymbol{c} + \boldsymbol{e_m}$$

$$RSTD_{i,j}^{n} = \sqrt{\left(x_{RSU_i} - x_n\right)^2 + \left(y_{RSU_i} - y_n\right)^2}/c - \sqrt{\left(x_{RSU_j} - x_n\right)^2 + \left(y_{RSU_j} - y_n\right)^2}/c + e_n, \quad (4)$$

where (x_{RSUi}, y_{RSUi}) and (x_{RSUj}, y_{RSUj}) are the known coordinates of the *i*-th RSU and *j*-th RSU respectively, and (x_m, y_m) and (x_n, y_n) are the coordinates of the *m*-th and *n*-th antenna respectively. As the displacement between any two antennas is known, the coordinate of *n*-th antenna can be expressed with the coordinate of *m*-th antenna, which does not create a new unknown value. So there are only two unknown values (x_m, y_m) with two independent equations from which to solve the equations. As a result, if two DAS antennas are mounted on a vehicle, only two RSUs are required for absolute vehicle positioning.

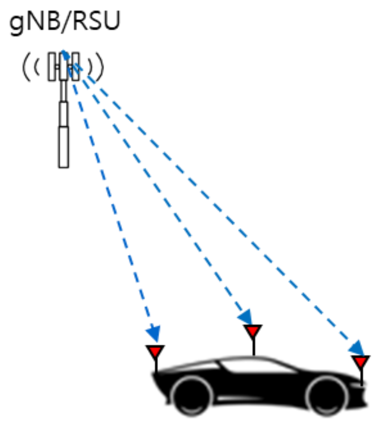


Figure 7.6.1-4 Example of positioning using DAS with a single gNBs/RSU

Even with a single RSU, the absolute vehicle positioning can be acquired if there are more than two distributed antennas mounted on a vehicle, as depicted in Figure 7.6.1-4. Two different pairs of the DAS antennas provide two independent RSTD equations, as follows.

$$RSTD_{i}^{m,n} = \sqrt{\left(x_{RSU_i} - x_m\right)^2 + \left(y_{RSU_i} - y_m\right)^2}/c - \sqrt{\left(x_{RSU_i} - x_n\right)^2 + \left(y_{RSU_i} - y_n\right)^2}/c + e_{m,n}$$

$$RSTD_{i}^{m,k} = \sqrt{\left(x_{RSU_i} - x_m\right)^2 + \left(y_{RSU_i} - y_m\right)^2}/c - \sqrt{\left(x_{RSU_i} - x_k\right)^2 + \left(y_{RSU_i} - y_k\right)^2}/c + e_{m,k}, \quad (5)$$

where $RSTD_i^{m,n}$ is the RSTD between *m*-th and *n*-th antenna over the *i*-th RSU, and $e_{m,n}$ is the estimation error in using *m*-th and *n*-th antennas. As stated earlier, the coordinates of all antennas can be represented by the coordinate of a ‘reference’ antenna and the displacement from that antenna. Again, there are only two unknown values (x_m, y_m) with two independent equations, so the equations can be solved. As a conclusion, if more than two distributed antennas are mounted on a vehicle, only a single RSU is necessary for absolute vehicle positioning.

The location of the distributed antennas on the vehicle may affect the positioning performance. There are two aspects that need to be considered in determining the antenna positions and the distance between the antennas – PRS receiving path discrimination and positioning diversity. As for the path discrimination, if the antennas is too close (e.g. back-to-back panel type), there may be almost no difference between TOA or AOA measured at each antenna over the PRS transmitted from the RSU. This causes difficulty in calculating the position of the antennas or the vehicle.

Concerning the positioning diversity, if the calculation is not possible with one of the DAS antennas (e.g. due to the insufficient number of RSUs), then the other antennas can be used for positioning measurement. This kind of diversity can occur if the distance between two antennas is too small (e.g. less than a half of the PRS wavelength). Considering all the aspects above, the maximum achievable distance between antennas is good for DAS-based sidelink positioning.

Ultimately, the main purpose for using DAS on a vehicle is to improve the performance of V2X communication. If a DAS is mounted on a vehicle, it can also be used for positioning. Therefore, the position and distance of DAS antennas is not only decided by the positioning performance but also by the V2X communication performance.

The RSU deployment technique detects the location of UEs in a specific scenario via customised RSU deployments. In some applications, the absolute position information is not necessary; some partial information about the terminal location may be enough. A customised RSU deployment can provide the required 'partial information' with other benefits, e.g. reduced power consumption, operational complexity, etc.

An example of RSU deployment technique is illustrated in Figure 7.6.1-5 for VRU detection on a crossing:

- Each VRU periodically transmits PRS with no additional operation.

 No additional power consumption due to PRS reception, location calculation, etc.

- Each RSU installed at the end of the crossing measures the ToA from the received signal/message and then the time difference between ToAs measured from both RSUs is calculated.
- From the calculated time difference, we can see if a VRU is on the crossing or not. For example, if the time difference is smaller than a threshold, we can conclude that a VRU is on crosswalk. On the other hand, if the time difference is larger than or equal to a threshold it is determined that the VRU is outside or not on the crosswalk.
- The RSU can send a warning signal to vehicles approaching the crosswalk.

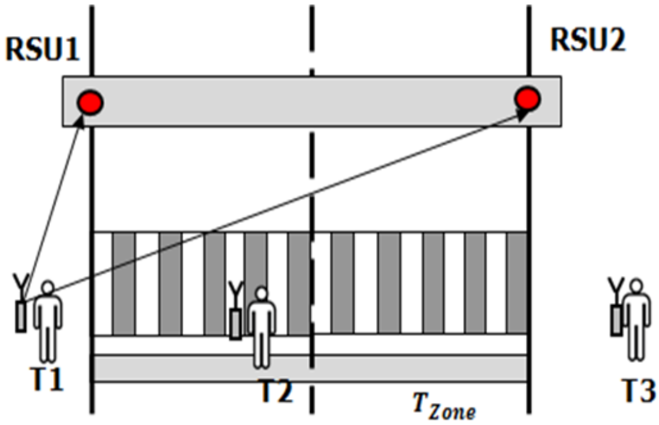


Figure 7.6.1-5 RSU deployment for VRU detection on the crossing

7.6.2 Synchronisation for positioning

Synchronisation systems are an important part of most, although not all, (e.g. not part of a multi-RTT mechanism) high-accuracy positioning systems, including both satellite navigation positioning and ground-based high-accuracy HAP system. Every 3ns decrease in the synchronisation of a high-accuracy positioning system will lead to a range error of about 1m. Therefore, synchronisation performance has become a key index of HAP systems, and the highly accurate synchronisation technology between ground positioning network elements is key. V2X needs to meet the information exchange requirements of future intelligent driving, and the need for synchronisation is obvious.

Since the positioning accuracy should be within 3-5m to meet most positioning requirements of future intelligent transportation, and a margin should be considered for error measurement, the synchronisation accuracy of about 3-10ns is needed to realise the positioning accuracy of 3m or even within metres for the operator-level ground positioning network.

Besides the time error budget of the positioning system/equipment, time synchronisation requirements and accuracy levels for HAP synchronisation equipment are shown in Table 7.6.2-1.

Table 7.6.2-1: Time synchronisation accuracy level for high precision positioning

Level of accuracy	Time error between interfaces of a device	Time error between interfaces of different devices (Note)
A	±1ns (Positioning accuracy 1m)	additional time error ≤ ±5ns
B	±5ns (Positioning accuracy 3m)	additional time error ≤ ±5ns
C	±10ns (Positioning accuracy 5m)	additional time error ≤ ±5ns
Note: This is an additional time error that can be introduced based on the index of ‘Time error between interfaces of a device’.		

According to ITU-T Recommendation, the time synchronisation requirement from time reference source to end application (i.e. base station) for communications is ±1us, which is an absolute time synchronisation accuracy. The highest time synchronisation accuracy between different base stations is ±32.5ns, which is a relative time synchronisation accuracy. Although high-accuracy vehicle positioning only requires relative time synchronisation, the time synchronisation requirement of the communication network is much lower than that of high-accuracy vehicle positioning. The synchronisation technology adopted by the existing 3G/4G can only achieve a 100ns level of accuracy, and cannot provide the high-accuracy positioning capability of the vehicle in metres.

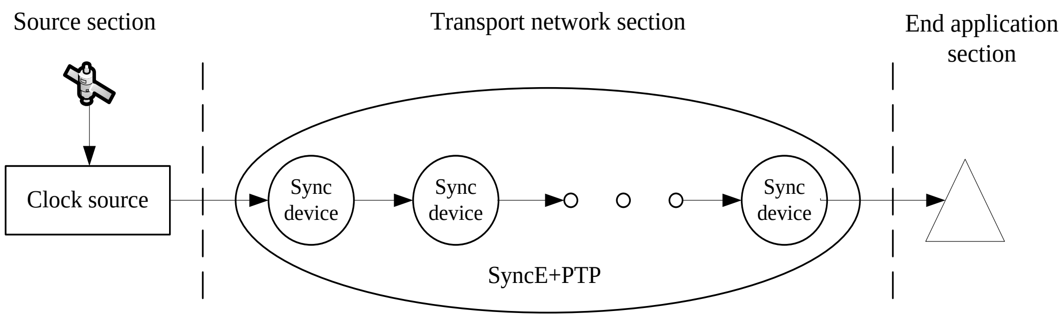


Figure 7.6.2-1 Ground synchronisation network division

As shown in Figure 7.6.2-1, the synchronisation network can be divided into: source section, transport network section and end application section. In a communication network, an end application device is a communication base station. In a positioning application, an end application device is a positioning system or device.

To meet the synchronisation requirements of high-accuracy vehicle positioning and improve the overall accuracy of the synchronisation network, the following technical aspects are developed:

- Source section: Satellite timing technology, clock source.
- Transport network section: Time synchronisation protocol, performance of synchronisation device, optical fibre asymmetry.

High-accuracy vehicle positioning imposes higher requirements on synchronisation technologies than communication networks, and is an important requirement for 5G. To meet the expectations of high-accuracy vehicle positioning on the metre level, all sections of the synchronisation network need overall technical improvement:

- Source section: More accurate source technologies should be used, such as satellite common view timing technologies.
- Transport network section: SyncE is used for frequency synchronisation, and PTP is used for time synchronisation. Synchronisation devices need to improve in performance. The single-fibre bidirectional technology must be used between devices.

Figure 7.6.2-2 is a time synchronisation networking model. The bearer synchronisation device directly connected with the end application device (e.g. positioning system) can be an intermediate device, not necessarily an end device of the transport network. One bearer synchronisation device can be connected with multiple end application devices.

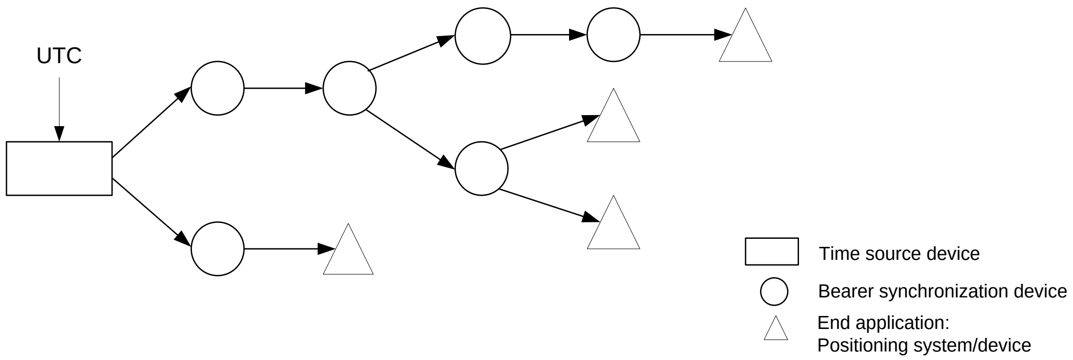


Figure 7.6.2-2 Time synchronisation networking model

All levels of synchronisation networks in the entire communication network can be expanded as the above time synchronisation networking model, meaning that each bearer synchronisation device can connect to a positioning system/device.

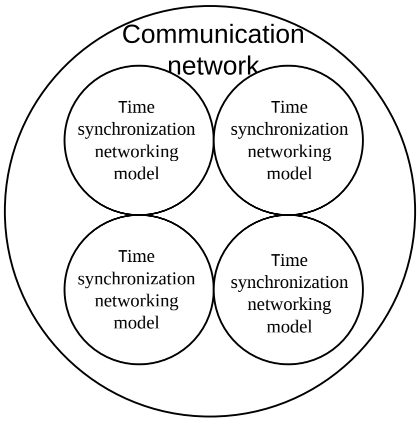


Figure 7.6.2-3 Extension of the time synchronisation network model

The features of a ground communication synchronisation network, such as wide coverage, stable and reliable signals, and few environmental factors, can provide better support for high-accuracy vehicle positioning.

7.6.3 Cooperative positioning among terminals

Cooperative positioning is a solution that improves the accuracy, reliability and availability of positioning by sharing positioning-related information among neighbouring terminals. This information includes the absolute position, relative position, or the data for location error compensation according to positioning scenarios/use-cases for cooperative positioning. For instance, by sharing positioning-related sensor information via communication link with other terminals in the surroundings, this technique can mitigate or overcome accuracy performance degradations caused by the limitations of on-board sensors regarding their detection range, angle of view and facility blockage.

The positioning-related information can be exchanged via backend interaction, or directly exchanged between terminals, or the positioning-related information from each terminal can be delivered to the network or RSU, and the aggregated information can be transmitted to the nearby terminals. In this sense, and considering the sidelink scenario, this cooperative positioning technique can be distinguished from the sidelink positioning technique in that there is no S-PRS transmission from terminals or RSUs. Figure 7.6.3-1 shows an example of cooperative positioning, where three GNSSs and two vehicles (vehicle A, vehicle B) are considered, and vehicles have an on-board ranging sensor. The overall positioning procedure example can be described as follows:

- Vehicle A calculates its absolute position using GNSS receiver.

- Vehicle A estimates vehicle B's absolute position through the ranging sensor and geomagnetic sensor.
- Vehicle A shares the estimated absolute position with vehicle B via sidelink.
- Vehicle B calibrates/updates its absolute position considering the shared information.
- Vice versa operation from vehicle B to vehicle A.

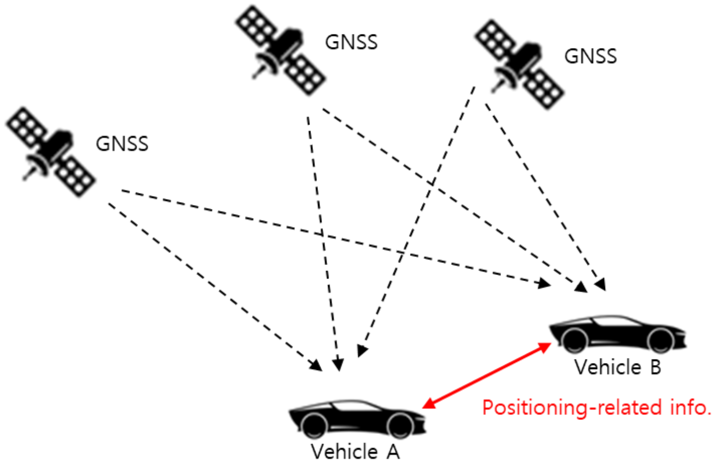


Figure 7.6.3-1 An example of cooperative positioning

The above figure and procedure are just an example of the cooperative positioning. Absolute/relative position information or the ToA and AoA/AoD measurement of each terminal can be shared with other terminals for better positioning.

7.7 Vehicular positioning using 5G millimetre-wave and sensor fusion in highway scenarios

High-accuracy positioning and the kinematic state of the vehicle are critical pieces of information for safety applications. When it comes to radio-based positioning techniques, there have been important studies especially considering the huge improvements in capacity, number of connected devices, and latency introduced by 5G systems. Recent research shows that features such as using millimetre-wave (mmWave) bands and multiple-input-multiple-output (MIMO) features make 5G mmWave systems favourable for sub-metre accuracy positioning 0.There are many reasons for this assumption. The large bandwidth available to mmWave frequencies enables more accurate estimation of time of arrival or time difference of arrival measurements. For mmWaves, more antennas can be packed in the same area and this enables accurate estimation of angle of departure and angle of arrival estimations. Hence, the combination of AOD or AOA with TOA makes position estimation theoretically possible, also with a single anchor mmWave systems. Studies on theoretical error bounds have shown that mmW systems are capable of locating a UE with sub-metre positioning error and sub-degree orientation error [30].

An aspect to consider is the case of reduced coverage (e.g. in tunnels) which might add some issues for GNSS- and radio-based positioning techniques. A possible approach to overcome this limitation is to take advantage of sensor data available via the vehicle and to use it for improving positioning accuracy in situations of limited coverage. In particular, one approach is to fuse range- and angle-related measurements routinely exercised by 5G mmWave cellular base stations with acceleration measurements available from the vehicles. The fusion of such measurements can be obtained by using extended Kalman filters **Error! Reference source not found.**0. This has been investigated in details in [29], whch provides some key information on this approach and preliminary simulation results.

In the proposed position estimation approach, the focus is on the downlink of a MIMO system considering a highway scenario. The positioning is hence UE-centric, where the UE computes its position by fusing position-related network information including the position of the BS with IMU information. The system architecture and the data flow of the proposed method is summarised in Figure 7.7-1.

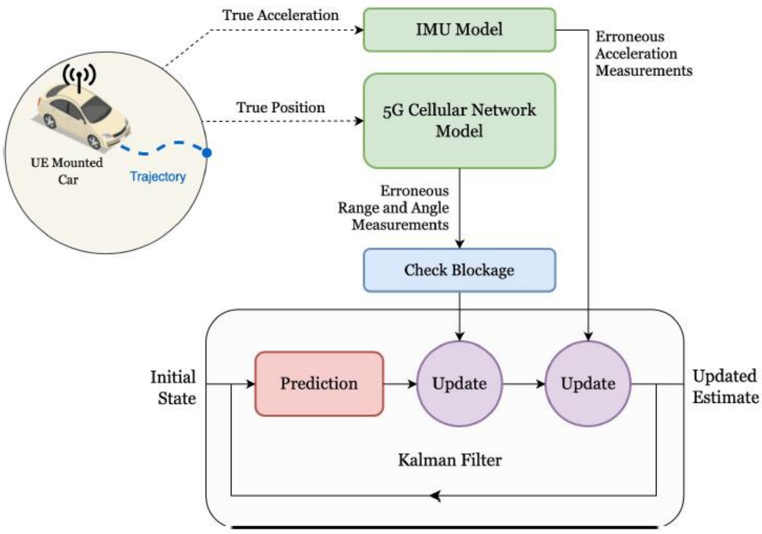


Figure 7.7-5: System architecture and data flow for fusion-based positioning method

The system is composed of five separate components: inertial measurement unit (IMU) model, cellular network model, blockage model, Kalman filter, and the vehicle mounted UE.

The IMU measures the acceleration/deceleration of the vehicle. The cellular network provides measurements of the range and the AOD corrupted by a Gaussian error. The AOD aims to exploit the potential of more accurate AOD computation at base stations considering antenna systems with large numbers of antenna.

In the approach investigated here, the position is computed by fusing information on BS position, range of measurement, AOD, and the acceleration/deceleration information of the vehicle.

A line of sight (LOS) communication model with blockages is assumed, as illustrated in Figure 7.7-3. It is also assumed that the base stations are located close to the highway. We consider that the UE is connected to the BS from which it receives the strongest signal, and the BS to which the UE is attached is used to calculate the parameters (range and angles). The other BSs are taken into account in calculating the interference.

In order to simulate a single anchor positioning system, we need to generate angle a_k and range r_k samples. As shown in Figure 7.7-2, for generating the samples at time step k, an ideal estimator adds white Gaussian noise to the true angle and range values of the UE in the form of

$$r_k = \rho_k + \sqrt{\left(x_{R,k} - x_T\right)^2 + \left(y_{R,k} - y_T\right)^2}, (1)$$

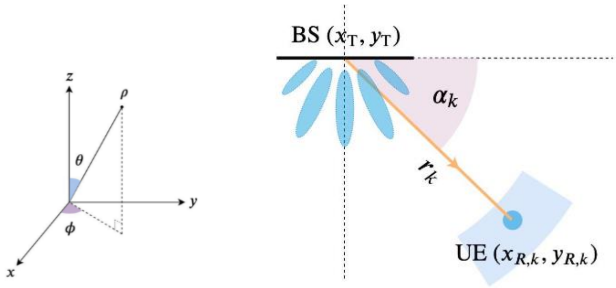
$$a_k = \alpha_k + \arctan(\frac{y_{R,k} - y_T}{x_{R,k} - x_T}), (2)$$

where $\rho_k \sim N(0, \sigma_\rho^2)$ and $\alpha_k \sim N(0, \sigma_\alpha^2)$ are white Gaussian samples of range and angle, respectively, with the standard deviation given by

$$\sigma_\rho = \left(\sqrt{CRLB(\tau)} \times c\right) \times sin\theta_T, (3)$$

$$\sigma_\alpha = \sqrt{CRLB(\phi_T)}, (4)$$

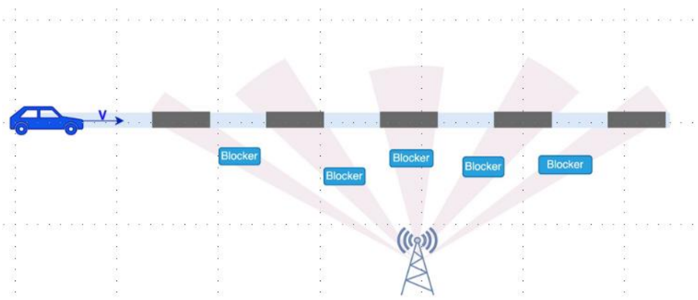
where c is the speed of light, Cramer-Rao lower bounds (CRLBs) are obtained from the closed-form formulas in [30], and calculated using the setup parameters and the position and orientation of the UE. One can note that σ_ρ depends on the TOA indicated as τ. Multiplication of $sin\theta_T$ is necessary because the CRLB is calculated in 3D space and the result should be on 2D xy-plane, where θ_T indicates the AOD in the zy-plane. One can note that σ_α depends on the ϕ_T which indicates the AOD in the xy-plane. The noiseless terms of Equations (1) and (2) are true range and true angle of the UE from the connected base station.



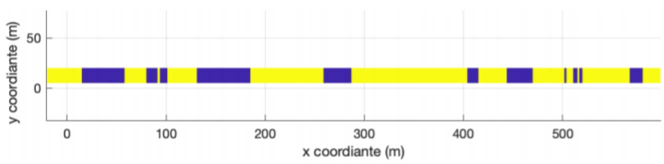
(a) (b)

Figure 7.7-2: (a) Spherical coordinate system and (b) 5G range r_k and angle α_k measurement model

Since there are no standardised LOS blockage models for the highway scenario, the rural macro (RMa) model defined in 3GPP is considered as a LOS probability model. The 3GPP RMa model provides the LOS probability Pr_{LOS} parameter and given that the 3GPP RMa model on LOS blockage does not provide information about the duration or probability of arrival of the blockage, the following parameters have been added: blockage average distance μ, and the average number of blockage events per meter λ. The parameter $\mu(x)$ can be derived from the equation $Pr_{LOS}(x) = 1 - \lambda \times \mu(x)$, where x would represent $d_{2d}(x)$ (i.e. the distance between the UE and the BS on xy-plane for each point of the highway[1]). By tuning μ and λ, the LOS blockage model can be extended to consider long and less frequent blockages in addition to short and frequent blockages. According to this model, when the distance of the UE from the BS increases, the recurrence of blockage events is expected to increase as well as the length of the blockage events. Although not fully reflecting a real-case scenario of blockage in highway scenarios, this allows us to consider the case of different lengths for blockage duration. More analyses would be required considering a more accurate blockage model for highway scenarios.



(a)



(b)

Figure 7.7-3: Simplified illustration of the LOS blockage model (a). Example of LOS blockage pattern (blocked areas are in yellow) with settings λ = 0.04 m^{-1}, the average blockage duration μ = 20 m, LOS blockage probability = 80% (b)

A Kalman filter is an algorithm that estimates the parameters of the system given the initial state and the subsequent measurements/observations. The initial state contains the position of the vehicle, its velocity and the acceleration in (x, y). Based on the initial step a) prediction on the systems' parameters are made. Then, the measurements from the IMU

[1] For simplicity, it is assumed that the vehicle is moving over the *x*-axis.

and the cellular network are made and used in combination with the prediction results to calculate the updated state. The update state gives the estimate of the parameters.

In the following we present some simulation results. A snake-shape trajectory of 3km with sharp turns and harsh brake intensities is considered, with an average speed of $v = 130\ km/h$ is swerving in curves each with the length $l = 20m$ and width $w = 5m$. At every other turn the linear speed is reduced by a factor of 25% to simulate the braking. For cellular system cases, it is assumed 64 antennas are at the base gNB, and four antennas at the UE. The study assumes reference signals use three out of 12 subcarriers in a PRB[2]. An overall bandwidth composed of 275 PRBs is considered, which results in 49.5MHz bandwidth in cmWave and 198MHz bandwidth in mmWave, wherein a portion of this bandwidth is used for carrying reference signals used for positioning. The transmitting power is set to 45dBm for cmWave and to 30dBm for mmWave. The cmWave frequency is equal to 3.5GHz and the mmWave one is 28GHz. The inter-site distance (ISD) is equal to 1732m for the cmWave and 500m for the mmWave[3]. In the following, it is considered a limited sampling frequency, i.e. 245.76MHz for mmWave, and the sampling frequency limits the range measurements' accuracy to 1.22m in mmWave scenario (please note that AOD is not affected by sampling frequency). The aim of this study is to highlight that by using an approach based on data fusion, positioning accuracy can be improved to overcome the limitations of range measurement accuracy due to limited sampling frequency.

Simulations considered first of all GNSS-related performance. In the GNSS-only scenario, an error up to 4-7m was achieved on the x-axis and y-axis, respectively. The average error was around 1m and 1.5m on the x-axis and y-axis, respectively. Finally, a 90th percentile error (around 2m and 3.5m) on the x-axis and y-axis were obtained respectively. Simulations were conducted to analyse the performance of a scenario where GNSS is combined with IMU. Results showed an error up 1.2m for both x-axis and y-axis. The average error was of about 0.4m for both x-axis and y-axis. Finally, a 90th percentile error of around 0.7m on both x-axis and y-axis was obtained.

Simulations for cellular-based positioning focused on the performance when combined with IMU, considering the cases of cmWave cellular and mmWave cellular combined with IMU. In this first comparison it is assumed that the cellular-based positioning is performed with no blockage (Pr_{LOS} = 0). A second comparison assumes that the cellular-based positioning is performed with blockage Pr_{LOS} = 0.5.

Figure 7.7-4 and Figure 7.7-5 show performance in the event of no blockage (Pr_{LOS} = 0) for cmWave cellular and for cmWave cellular, respectively. Results for cmWave cellular show an average x-axis error around 0.1m and y-axis error around 0.5m. Results for cmWave cellular show a 90th percentile error of around 0.25m and 1.1m for x-axis and y-axis, respectively. Results for mmWave cellular show an average x-axis error around 0.07m and y-axis error around 0.15m. Results for mmWave cellular show a 90th percentile error of around 0.15m and 0.38m for x-axis and y-axis, respectively.

Figure 7.7-6 and Figure 7.7-7 show performance in the event of blockage (Pr_{LOS} = 0.5) for cmWave cellular and for cmWave cellular, respectively. Results for cmWave cellular show an average x-axis error of around 0.5m and y-axis error of around 0.75m. Results for cmWave cellular show a 90th percentile error of around 1.1m and 2.1m for x-axis and y-axis, respectively. Results for mmWave cellular show an average x-axis error of around 0.15m and y-axis error of around 0.2m. Results for mmWave cellular show a 90th percentile error of around 0.3m and 0.4m for x-axis and y-axis, respectively.

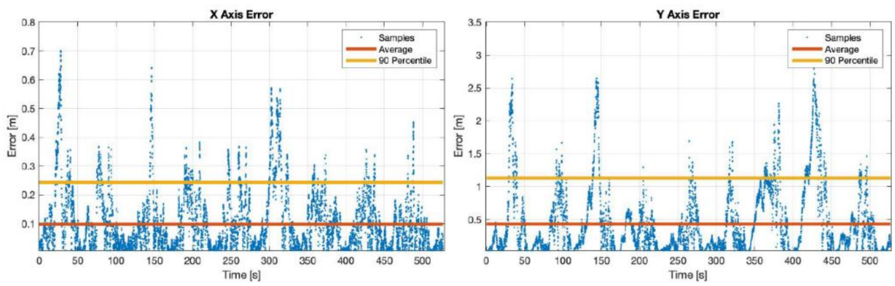


Figure 7.7-4: Results for cmWave cellular combined with IMU scenario (Pr_{LOS} = 0)

[2] The bandwidth of each PRB is 180kHz for cmWave and 720kHz for mmWave, corresponding to the sub-carrier spacing (SCS) of 15kHz and 60kHz, respectively.

[3] Please note that LOS is affected by ISD of base station deployments. Densification of deployment (e.g., RSU-like deployment along the highway) could be considered to guarantee higher probability of LOS for vehicles. Cost of densification of network deployment may be different for cmWave and mmWave, with higher densification cost for the mmWave case.

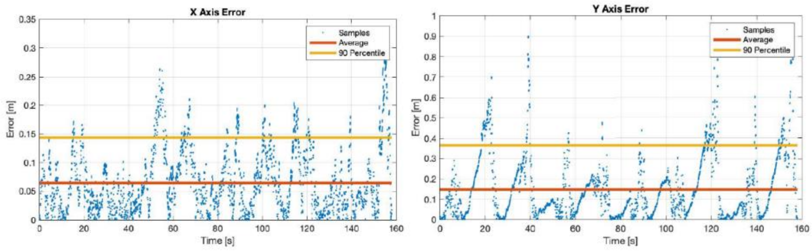


Figure 7.7-5: Results for mmWave cellular combined with IMU scenario (Pr_{LOS} = 0)

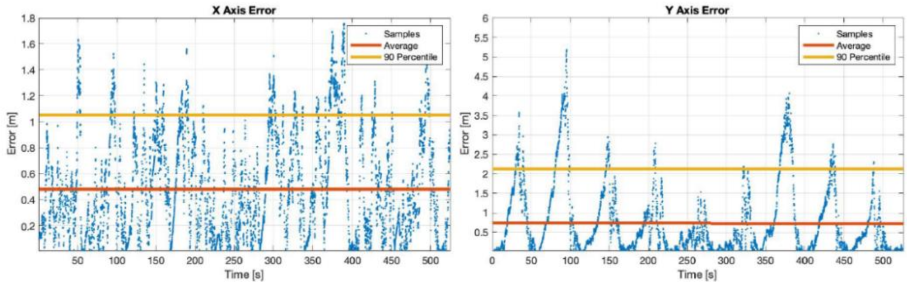


Figure 7.7-6: Results for cmWave cellular combined with IMU scenario (PrLOS = 0.5)

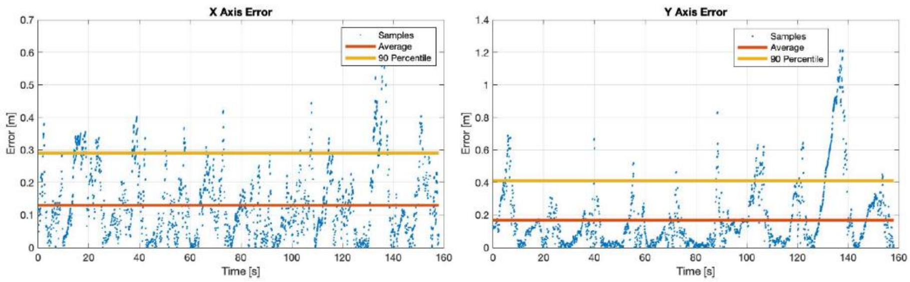


Figure 7.7-7: Results for mmWave cellular combined with IMU scenario (Pr_{LOS} = 0.5)

Further analyses have been conducted regarding the impact to performance of the proposed approach with data fusion for positioning, when increasing the bandwidth used for reference signals. With the sampling frequency limit, i.e. 61.44MHz for cmWave and 245.76MHz for mmWave, the major accuracy gain happens when the bandwidth used for reference signals is increased up to 4.86MHz for cmWave (out of 49.5MHz overall bandwidth) and up to 19.56MHz for mmWave (out of 198MHz overall bandwidth), allowing accuracy to improve from metre-level to decimetre-level (in particular, average accuracy of 0.9m for cmWave and 0.3m for mmWave for cases with LOS blockage). When the bandwidth used for reference signals increases further, only gains for positioning accuracy are seen in the order of few centimetres and this holds for both cases with and without LOS blockage.

The preliminary simulation results of the study presented above shows that positioning information from a single 5G base station (providing BS position, range and AOD measurements) fused with IMU sensor data could be effective in providing adequate positioning accuracy, as well as in compensating for occasional LOS blockages. Particularly for mmWave systems, this approach is able to reach sub-metre level precision also in signal blockage cases. But it needs be noted, the above simulation studies are based on theoretical error bounds [30]. Analyses would be required to further validate and improve these results, considering implementation limits of UEs and base stations, as well as the impact that blockage length has on the accuracy of the IMU model.

8 Testing and demonstration

8.1 Evaluation of RTK systems based on cellular networks

RTK systems based on the cellular network mainly serve to complete the rapid deployment of reference stations. Through the wireless network backhaul, the rapid and flexible deployment of reference stations can be achieved without being restricted by the distribution of optical fibres. In this system, the data received by the reference station is transmitted to the server through the wireless communication system. Then the server implements the data processing, and sends the values to the user terminals. The functions of each part are shown in Table/Figure 8.1-1.

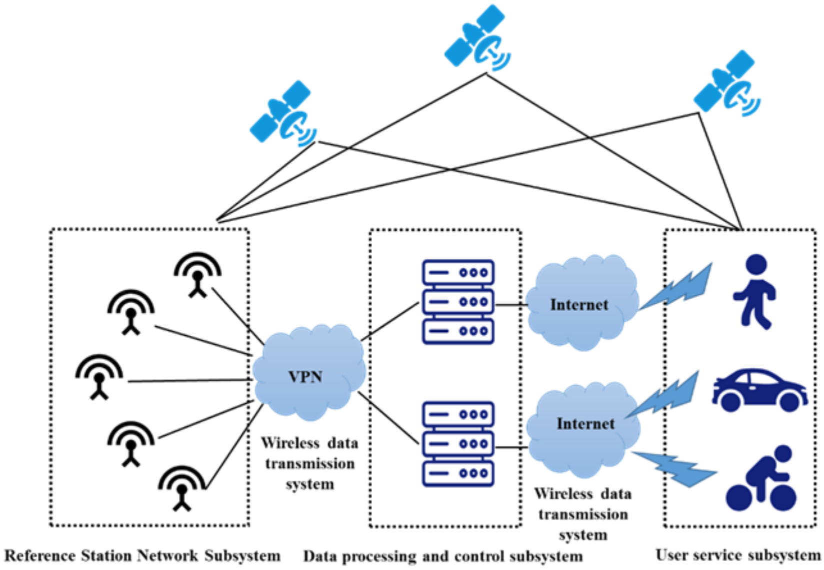


Figure 8.1-1 RTK network architecture diagram based on cellular network

Table 8.1-1 RTK network elements based on cellular networks

Subsystem	Function
Reference station network subsystem	Satellite positioning data acquisition
Data processing and control subsystem	Receive the data from the reference station, check the working conditions of the reference station, remotely control the reference station and users; analyse, process, store and manage the data; form the data file in a certain format and send it to the user
Wireless data transmission system	Reference station network: connects the reference station subsystem with the data processing and control subsystem, transmits the data including GNSS observation data and remote control data; User network: obtains the differential data from the data processing and control subsystem through the cellular network
User service subsystem	Manage users through operation service software and provide GPS/Beidou high-precision services

The test of this approach has been carried out in Fangshan Science and Technology Park in Beijing using two positioning boards of the same model and version.

A pair of mushroom-head antennas were employed and connected to two devices through a power divider. One device used a commercial differential service system and one used the rapidly deployed differential system. The two antennas were fixed on the top of the same car, with the positioning error of about 10cm.

Figure 8.1-2 Dynamic test effect chart

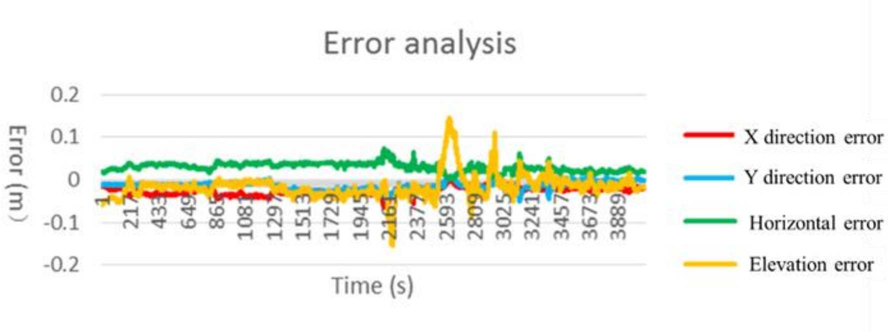


Figure 8.1-3 Error analysis chart

Statistics on network performance showed that the minimum observed delay is 199ms, the maximum delay is 603ms, with an average delay of 333ms. The probability of less than 300ms is about 66% and the probability of less than 500ms is about 68%.

8.2 Vehicle-pedestrian anti-collision

On 7 June 2017, a vehicle-pedestrian anti-collision test based on cellular network was conducted at National Intelligent Connected Vehicle (Shanghai) Pilot Demonstration Area by China Unicom and several partner, Tsinghua University, Nebula-Link, Datang Telecom, ZTE, Ford (China) and China FAW. This anti-collision solution was achieved on the basis of China Unicom's LTE network, high-accuracy positioning and path tracking technology and LTE-V2X equipment and application server.

In this vehicle-pedestrian anti-collision solution, the pedestrian movement status information, coming from GPS, is transmitted to the RSU through an LTE network, and the RSU then broadcasts the movement status information to vehicles at intersections. After receiving the pedestrian movement information, the vehicle makes a decision based on a collision-avoidance algorithm; a buzzer/sound and screen warning is triggered if the pedestrian is at risk of being struck. The positioning of pedestrians, with metre-level accuracy, is realised through GNSS.

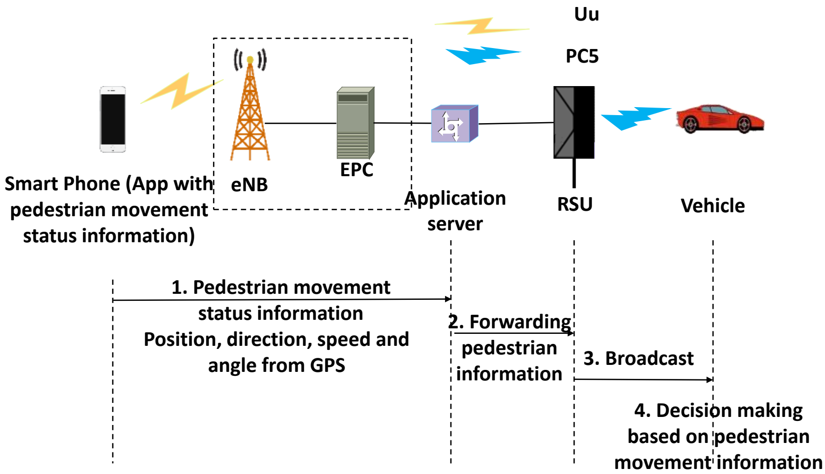


Figure 8.2-1 Communication process of vehicle-pedestrian anti-collision

8.3 Parking management based on 5G high-accuracy positioning

At the end of 2019, ZTE and China Unicom Wuhu Branch launched a 5G-based high-accuracy positioning demonstration in the industrial area of Wuhu Meizhi Co. Ltd. By deploying six positioning base stations capable of 3.5GHz band signal in the parking area of the industrial park, coverage of the whole area (320m X 50m) is possible.. This solution achieved accurate positioning of 44 parking spaces.

After dozens of positioning tests for each parking space, over 95% accuracy was achieved, i.e. each parking space measuring 2.8m wide and more than 95% positioning measurement error is less than + / - 1.4m. Based on this finding, the six base stations met the demand for parking in the Wuhu Meizhi industrial park.. In addition, real-time tracking of the test vehicle and its time spent in the parking space were also carried out.

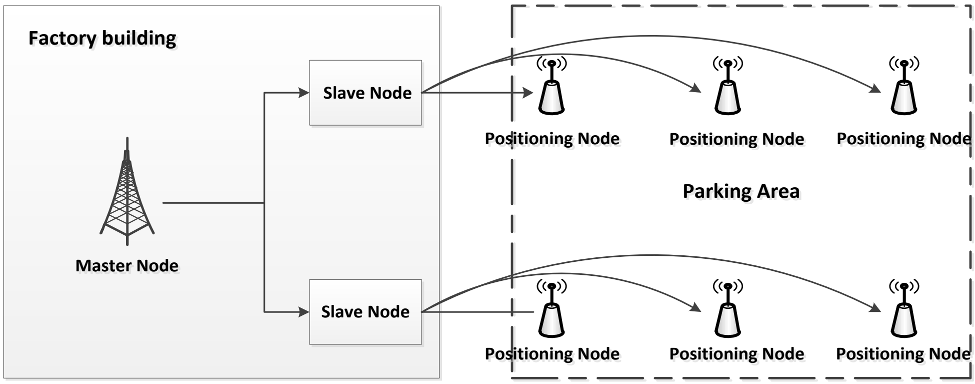


Figure 8.3-1 Deployment of 5G high-accuracy positioning

8.4 V2X application based on high-precision positioning

In September 2019 at the Wuxi IoT Conference, NavInfo and Sixents Technology jointly demonstrated the V2X overall solution of high-precision map + high-precision positioning in the Wuxi car-connected city-level demonstration area.

In the joint test ground – a 10km area in Wuxi Municipality – the high-end positioning system located on the vehicle used the GNSS RTK and IMU integrated positioning solution to deliver the vehicle's position, attitude, speed, and time information. The RTK correction service used the GNSS reference station ground-enhancement system deployed in the area by Sixents Technology to track GNSS satellites in the field of vision, and used centralised data processing and classification to obtain error correction parameters and integrity information sent to the host through the communication network. Vehicle GNSS terminal equipment was thus shown to improve vehicle positioning accuracy and help to maintain real-time lane-level positioning. Combined RTK and IMU positioning provided integrated navigation for complex urban environments, and it also provided continuous and reliable high-precision positioning results even under weak satellite signal coverage scenarios, such as overhead occlusion, short tunnels and urban canyons.

The RTK correction service guaranteed better vehicle position accuracy and demonstrate V2X applications in positioning, so as to improve vehicle driving safety and road traffic efficiency. And by matching GNSS RTK positioning with high-precision maps, more application scenarios can be achieved.

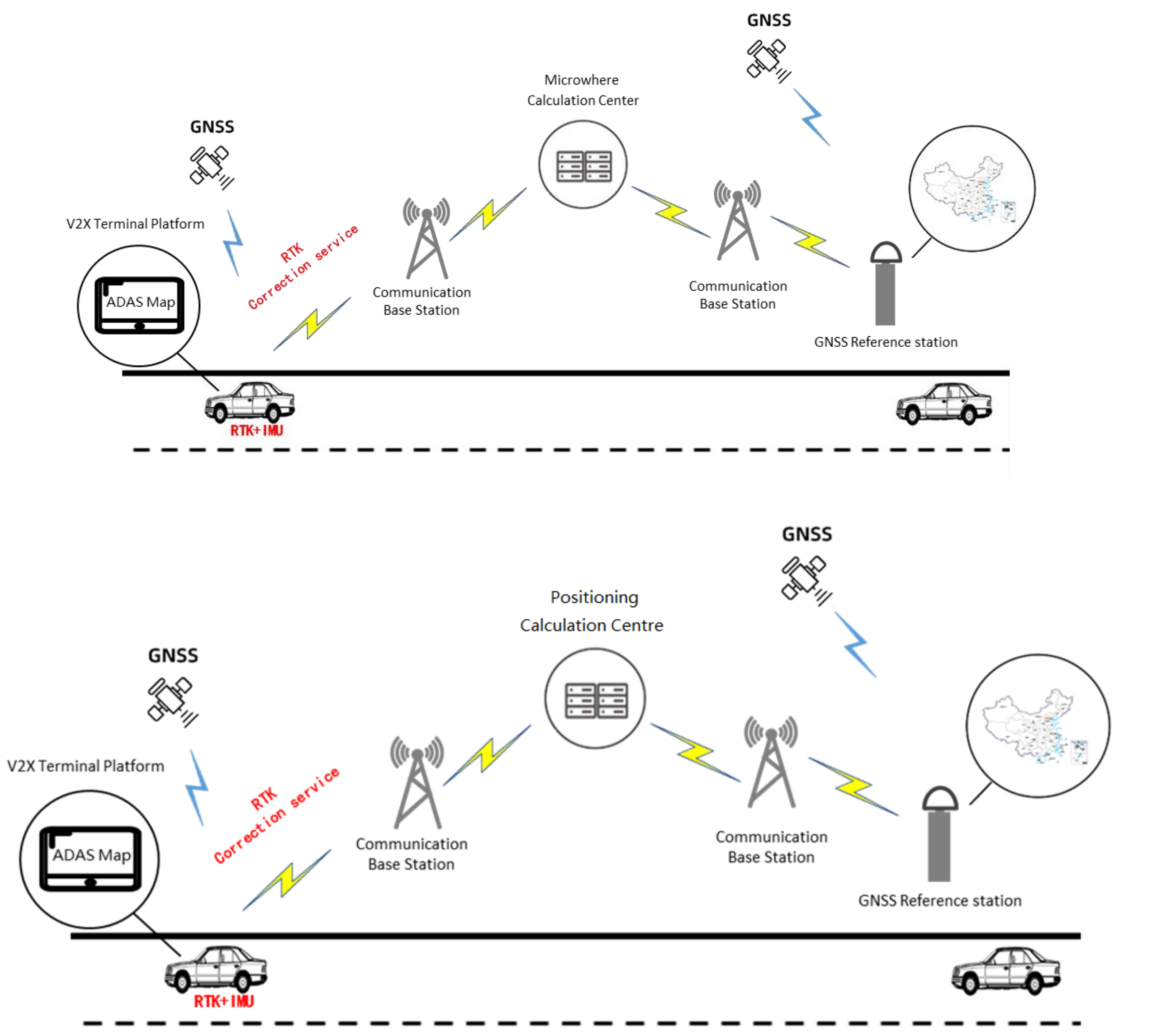


Figure 8.4-1 RTK + IMU integrated positioning solution

9 Conclusion

This study focuses on research into high-accuracy positioning (HAP) for V2X services.

The importance of high-accuracy positioning research and positioning schemes is summarised in Section 4.

Positioning requirements for three types of C-V2X scenario and the challenges of positioning in different C-V2X settings is outlined in Section 5.

Section 6, meanwhile, describes three system architectures for C-V2X positioning:

- UE-based positioning architecture: Calculating position on the terminal side; the network is mainly responsible for GNSS data transmitting and 5G-based positioning, and the terminal is mainly used for GNSS positioning and fusion algorithms.
- UE-assisted positioning architecture: Calculating position on the network side; the network realises GNSS positioning, 5G-based positioning, the fusion algorithm and the transmission of positioning results, and the terminal provides measurement reports and receives positioning results.
- Sidelink positioning architecture: The three operations include the sidelink positioning configuration, the S-PRS transmission, and measurement and position calculation. Considering that both configuration and calculation can be completed by the network or UE itself, there are four kinds of sidelink positioning architectures.

In Section 7, several key HAP technologies for C-V2X are introduced:

- High-accuracy GNSS based on a differential system.

  In, Section 7.2.1, the mechanism of broadcasting differential correction data over cellular networks is introduced.

  - Characteristics: The correction calculation platform receives the original satellite observation data to form difference correction information. When there is a request from the terminal the platform sends it through the cellular network by matching the corrections corresponding to terminal locations.
  - Performance: Centimetre-level accuracy.
  - Standardisation: Standardised algorithm has been completed.
  - Trials/deployment: Widely deployed.

  Section 7.2.1 also includes a scheme for when RSUs request the differential correction information from a cloud platform and broadcast them directly to terminal devices via sidelink. Compared to the unicast-based solution so described, it reduces the E2E latency for the positioning acquisition, which improves positioning accuracy as a result. The differential correction is to be included in the extended message sets defined for ITS applications, e.g. [31], which will be frozen at the end of 2020.

  Section 7.2.2 describes GNSS location based on SSR services.

  - Characteristics: UE determines its absolute position in a global reference frame (e.g. ITRF) using GNSS assistance data from the network. The RTK method differentially adjusts the GNSS observations of the UE based on the known location of surrounding base stations. The SSR method broadcasts to the UE the error state profile (orbits, clocks, biases, ionosphere, troposphere, etc.) across the network coverage region.
  - Performance: RTK and SSR enable sub-decimetre absolute positioning in real time. Bandwidth is typically in the order of <2kbps for RTK and <1kbps for SSR. SSR performance can be configured (e.g. lower accuracy, less bandwidth) using a subset of error states.
  - Standardisation: A complete standard for RTK and SSR is specified for the LTE Positioning Protocol (LPP) in 3GPP Release 16. Release 17 will extend LPP with GNSS integrity assistance data.
  - Trials/Deployments: Localised government and commercial RTK networks are operational and continue to expand in coverage. Commercial SSR networks are now operating at continental scales. GNSS positioning using 3GPP standards is a core objective and principle of the '5GAA Precise Positioning for C-V2X' (PPL) Work Item.

- Visual positioning based on sensors and a HD map.

  - Characteristics: According to the object position information in the HD map and the sensor measurement results, vehicle position information is calculated. Combined with the RTK positioning result and vehicle prediction state, the final positioning and status update is obtained.
  - Performance: Centimetre-level positioning can be achieved.
  - Standardisation: N/A
  - Trials/Deployments: Currently, there are some test cases, such as the V2X application demonstration of a high-precision map in Wuxi (as seen in Section 8.4).

- Cellular network location service.
  - Characteristics: Location services based on a cellular network can determine the geographic position of mobile users through the radio signals.
  - Performance: Tens of metres accuracy in LTE, metre accuracy in 5G.
  - Standardisation: The LTE positioning standard has been completed in Release 14. NR positioning requirements and technology enhancement have been finalised in Release 16. NR positioning will be further developed in Release 17.
  - Trials/Deployment: Rarely used at present, but there are some positioning trials, e.g. the 5G indoor positioning system test in Tianjin Binhai New Area. (http://tj.people.com.cn/n2/2019/0508/c375366-32915545.html)
- Sidelink positioning and other positioning accuracy improvement schemes.

  In Section 7.5.1 and 7.5.2, sidelink positioning for V2X leveraging vehicle dynamics is outlined, and in Section 7.5.3, the spectrum requirements for sidelink positioning is addressed.
  - Characteristics: Relative and absolute positioning is obtained based on positioning reference signals sent on sidelink. The network and UE calculate the UE's location in sidelink-assisted and sidelink-based positioning, respectively.
  - Performance: The target requirement is sub-metre accuracy and is achievable with adequate bandwidth for positioning reference signal transmission.
  - Reference signals for positioning over sidelink is not standardised.
  - Trials/Deployment: Standards are still pending so there is no deployment currently underway.

  In Section 7.6.3, cooperative positioning among terminals and, in Section 7.6.1, antenna/RSU distribution/deployment techniques are addressed.
  - Characteristics: Positioning-related information (e.g. location, measurement and sensor data) sharing and the use of distributed antennas on the vehicle or RSU can be used for improving positioning performance.
  - Performance: Positioning error compensation using averages and anchor node synchronisation error mitigation; demanding fewer anchor nodes for absolute positioning (e.g. a single base station or RSU).
  - Standardisation: 3GPP Release 17 study on NR positioning support investigates the possibility of multi-panel-based positioning.
  - Trials/Deployment: Standards are still pending so there is no deployment currently underway.

  Section 7.6.2 presents a mechanism for improving positioning accuracy through synchronisation.
  - Characteristics: Synchronisation is a key index for HAP systems, such as satellite navigation positioning and cellular networks. V2X also needs synchronisation to meet the information exchange requirements of future intelligent driving.
  - Performance: Every 3ns decrease in the synchronisation accuracy of a high-accuracy positioning system will lead to a range error of about 1m.
  - Standardisation: ITU-T, 3GPP, IEEE, ORAN, CCSA and other standardisation and industry organisations are studying 5G synchronisation solutions.
  - Trials/Deployment: Realisation of high-precision synchronisation is difficult, so there is barely any deployment taking place at present.
- Vehicular positioning using 5G millimetre-wave and sensor fusion in highway scenarios.
  - Characteristics: UE-centric absolute position obtained by fusing position-related information with IMU information, suitable for both GNSS+IMU and 5G+IMU cases. For the 5G+IMU case, the UE computes its position based on PRS plus additional information provided by the base station (BS position, range and AOD

measurements). It is suitable for positioning with a single network anchor point and for short/medium out-of-coverage cases (e.g. tunnels).

- Performance: Sub-metre-level precision for the 5G+IMU case and for brief signal blockage (results based on simulation).
- Standardisation: For the 5G+IMU case, the solution works with 3GPP Release 15 PRS but requires additional BS-UE communication for positioning-assistance information (impact to standard not evaluated).
- Trials/Deployment: N/A

Regarding the 3GPP standardisation status on positioning, a study item (SI), identifying positioning use cases and requirements for V2X, has been approved in 3GPP RAN (Rel-17); the SI covers in-coverage, partial coverage, and out-of-coverage positioning use cases. In addition, an SI on NR positioning enhancements is on-going in 3GPP RAN1 and RAN2. The SI covers enhancement for high accuracy, low latency, network efficiency, and device efficiency for commercial use cases.

Lastly, some application demonstrations of vehicle positioning are shared in Section 8.

10 Work item leadership

5GAA WG2

New document				
Doc No.	Title	Lead WG	Start date + duration	Type of document & additional comments
WG2-00XX	Clarify positioning requirements and the positioning system architecture options. Provide the results and possible recommendations (TR)	WG2	M12 +6 (Q2 2020meeting) (M0=start date = October 2018)	Technical Report
WG2-00YY	White paper based on TR	WG2	M12+ 9 (Q3 2020)	White Paper

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