High Accuracy Positioning for C-V2X

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Abstract. With the rapid development and popularization of 5G and C-V2X, services based on C-V2X are rapidly expanding. Specially, the positioning accuracy is the most basic requirement in V2X service. According to the different requirements for V2X use cases, the positioning accuracies are also different. So the positioning schemes are various according to the positioning requirements. This paper contains a study of requirements, architecture, key technologies and demonstrations in high accuracy positioning for V2X services. Combining the scene analysis and performance requirements, high accuracy positioning, as a key part of the whole C-V2X system, its architecture can be divided into device-centric positioning architecture and network-centric positioning architecture. In addition, we summarize the key technology for high accuracy positioning of vehicles and demonstrate the proposal through testing.

1. Introduction
V2X promotes automated driving and enhance the traffic experience. The connection between cars, infrastructures, network as well as pedestrians enables a much more efficient and safer transport system. As one of the key components in V2X service, positioning information is indispensable for V2X use cases. There are multiple V2X use cases and positioning accuracies are different according to different services. The positioning accuracy requirements in typical use cases have been summarized in 5GAA [1] and some important KPIs for positioning have been described in 3GPP [2]. This paper aims to build the uniform understanding of the positioning requirements for different use cases to help set up the framework of positioning systems.

The positioning schemes are various according to the positioning requirements and environments. GNSS or its differential complement RTK, is the most basic positioning method. Considering that GNSS is not available in some scenarios such as tunnel or dense urban, its application scenario is limited to the outdoor environment. GNSS with appropriate corrections should be studied as part of the positioning solutions for C-V2X. Positioning based on sensors is another common positioning method for vehicles. However, the high costs and vulnerability to the environment also constrain its application prospect. 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 positioning techniques should be supported by some other assistive methods inertial navigation or HD map to ensure the positioning accuracy. Specially, cellular network is essential to enhance the positioning performance, such as the transmission of RTK data and the sensor data, download of HD map and even the fusion of the positioning data, etc.
2. System Architecture for V2X High Accuracy Positioning

With the rapid development and popularization of 5G and C-V2X, services based on C-V2X are rapidly expanding. Combining the scene analysis and performance requirements, high accuracy positioning, as a key part of the whole C-V2X system, its architecture can be divided into device-centric positioning architecture and network-centric positioning architecture.

2.1. Device-centric Positioning Architecture

Device-centric positioning is that the positioning calculation is completed at the terminal side by using the assisted information provided by the network such as RTK, map data, etc. [3]

Functions are taken as below in this architecture. For the network, it’s mainly used on RTK data transmitting and 5G-based positioning. And for the terminal, it’s mainly used on RTK positioning and fusion algorithm.

Assisted information for positioning can be obtained through eNB/gNB/RSU [4]. With the RTK information broadcasting through the RSU, the initial position information reporting of the terminal can be avoid. Meanwhile, the information collection and combination increase the terminal complexity.
Device-centric positioning architecture include terminal layer, network layer, platform layer and application layer, as shown in Figure 2.

Terminal layer - To meet 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 layer - Network layer mainly implements signal measurement and information transmission, including 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 map. 5G BS can also complete the signal measurement with the terminal and report platform. Platform compute the positioning values based on 5G signal to provide assistance for high accuracy positioning of vehicles. Based on 5G MEC (Mobile Edge Computing), real-time update can be realized on HD map. Real-time performance and accuracy will be greatly improved.

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

Road Side Unit (RSU) can realize RTK information broadcast, which avoids the reporting of the terminal’s initial position in the traditional RTK positioning. Meanwhile, RSU provides local road lane level maps and real-time dynamic traffic information broadcasts.

Platform layer - The platform layer can be modularized, including: HD map. Static HD map information, such as lane lines, lane center lines, lane property changes, etc. In addition, it also includes road parameters such as curvature, slope, heading, and cross slope, which enables the vehicle to accurately turn, brake, climb, etc. It also includes road signs such as traffic and road signs, and special certain points such as areas where GPS disappears and road construction status.

Dynamic traffic information, such as road traffic conditions, construction conditions, traffic accidents, traffic control, weather conditions, etc. [5]

Difference decomposition calculation. Platform continuously receives satellite data through RTK BS, and optimizes 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. Optimized spatial error will be sent to the vehicles.

Data management, such as 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. [6] These data are operating data which have been integrated and compiled after the data production process.

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

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

2.2. Network-centric Positioning Architecture

Network-centric positioning is that the positioning calculation is completed on the network side by collecting all the information from both the road side and terminal side. For the network, it is mainly used on RTK positioning, 5G-based positioning, fusion algorithm and positioning results transmitting [7]. For the terminal, it is mainly used on measurement report and positioning results receiving. And the positioning results can be transmitted to the terminal through eNB/gNB/RSU.

Layers in network-centric positioning architecture are similar as device-centric positioning. However, typical network-centric positioning scenarios include: vulnerable road users (VRU) and traffic supervision. It decreases the terminal complexity, and is suitable for high-precision positioning of pedestrians and non-motor vehicles in smart traffic.
Terminal layer - 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 layer and application layer are the same as device centric positioning architecture in the previous section.

Platform layer – In addition to the capabilities in the previous section, the platform layer also needs 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., based on which the platform provides users with a variety of services.

3. Key Technology for High Accuracy Positioning of Vehicle

3.1. 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 flow measurement station through the data communication link, and then the flow measurement station locates according to the correction data received.

Differential correction data broadcasting on user plane is a unicast transmission method based on protocols such as NTRIP and RTCM. The implementation steps are as shown in Figure 4:

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**Figure 3.** Signalling processing in the network-centric positioning architecture

**Figure 4.** Step of high-precision GNSS differential corrections broadcasting by the cellular network
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 [8]. 3GPP has evaluated positioning improvements for 5G New Radio in TR 38.855. On the one side, meter-scale accuracy requirements come from 911-emergency calls. For this, improvements to radio (RAN1) were proposed. For centimeter-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 analyzed in R1-1903022 [9] and R1-1902549 [10] where centimeter accuracy of the solution is confirmed. The LTE solution uses System Information Blocks (SIBs) that are broadcasted by cells and contain the RTK correction information allowing centimeter accurate positioning. SIB broadcast does not require (e)MBMS. It is part of the RAN control plane (Broadcast Control Channel) that is received by all UEs.

3.2. Location Service Based on Sensors and HD Map Matching

Visual positioning is to obtain visual images through sensors such as camera or lidar, then extract consistency information, and estimate the position of the vehicle according to the change of consistency information in the image sequence [11]. According to the strategy adopted in positioning, it can be divided into three methods: global positioning based on landmark database and image matching, SLAM based on simultaneous localization and map construction, and visual odometer based on local motion estimation.

Compared with traditional map, HD map applied to automated driving provides a richer semantic information, not only contains the driveway model such as the lane line, slope, curvature, heading, lane properties, connecting relation, but also includes a large number of positioning objects (object), namely, road, two side or at the top of the various static objects, such as the curb, barrier, traffic signs, traffic lights, telephone poles, gantry, etc. These elements contain precise location information, through the laser Radar (LiDAR), camera and millimeter wave Radar (Radar) to identify all kinds of static feature on the map, and then match these objects with the objects stored on the Map. After matching, the precise position and pose of the vehicle itself can be obtained through the relative attitude and position, so as to realize self-positioning without GPS, as shown in Figure 5.

![Figure 5. HD map matching and positioning based on semantic level](image)

The principle of HD map positioning based on semantic level is to obtain the positioning prediction value by inertial recursion or dead reckoning [12]. Then it positions through map matching and RTK, and filter fusion to correct the prediction result, and finally obtain accurate positioning information.

3.3. Location Service Based on Cellular Network

Location service (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 network of telecommunication operator (such as GSM/UMTS/CDMA/LTE/NR and other wireless network systems), and combine with an electronic map or other service for users [13].

Logical architecture of LCS based on cellular network is shown in Figure 6. Generally, basic positioning process is initiated by the location services client (LCS Client) sending location
information to the server. And the Location server execute measurement of the positioning target by configuring the wireless access network node, or obtains the location-related information from the positioning target by other methods. Finally, the location information is calculated and matched with the coordinates.

![Figure 6. Basic process of cellular network positioning](image)

Illustrated by the case of E-UTRAN positioning system, its architecture is shown in Figure 7. E-SMLC can be regarded as a location server of the control layer, which can be a logical unit or an entity unit. MME accepts requests from other entities or initiate positioning requests by itself; LMU (location measurement unit) is used to exchange measurement information, especial uplink location information with E-SMLC, and often combined with the eNB; SLP is an entity carrying SUPL protocol, which can usually considered as location server on the user plane; SUPL location information is interacted and transmitted on the user plane through the SUPL protocol; SET refers to the location target of the user plane.

![Figure 7. E-UTRAN positioning architecture (Source: 3GPP TS 36.305)](image)

On the communication protocol, signaling between UE and E-SMLC entity communicates by the LTE Positioning Protocol (LPP), between eNB and E-SMLC entity communicates by the LTE Positioning Protocol A (LPPa).

As shown in Figure 7, the E-UTRAN UE positioning process mainly refer to 5 functional entities: UE, eNB, Mobility Management Entity (MME), E-SMLC, and Evolved Packet Core Network Location Service Entity (EPC LCS).

Due to signal bandwidth, synchronization and network deployment, earlier cellular positioning systems often have tens of meters accuracy [14]. With the arrival of 5G, large bandwidth, multi-antenna and high accuracy synchronization technology, these supports will greatly improve the positioning accuracy to make up for the shortage of satellite positioning, especially in the indoor/tunnel scenario.

3.4. Sidelink Positioning

Conventional RAT-dependent positioning technique 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 PRS and doing measurement for terminal positioning. The measurement can include the ToA, AoA/AoD, RSTD, etc., measured by a terminal for ranging and positioning [15]. Similarly, such a sidelink could be promisingly exploited for positioning for C-V2X
by providing high reliability, accuracy and availability. In the sidelink positioning, sidelink will be exploited for the PRS transmission, and the positioning assistance data and the measurement can be transmitted on either sidelink or Uu link.

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 device-centric positioning where the positioning calculation is completed at the terminal side.

![Figure 8. An example of sidelink-assisted positioning mode](image)

### 4. Testing and Demonstration

#### 4.1. Evaluation of RTK System Based on Cellular Network

The RTK system based on the cellular network mainly completes 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 fibers [16]. 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.

For the cellular network, the data delay is required to be less than 50ms and the reliability is required to be more than 99%.

The test was carried out in Fangshan Science and Technology Park in Beijing. Two positioning boards of the same model and version were used for the experiments. 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 device used the rapidly deployed differential system. The two antennas were fixed on the top of the same car, and the positioning error is about 10cm.

![Figure 9. Error analysis chart](image)

Statistics on network performance show that the minimum delay is 199ms, the maximum delay is 603ms, and the average delay is 333ms. The probability of less than 300ms is about 66% and the probability of less than 500ms is about 68%.
4.2. Vehicle-pedestrian Anti-collision

On June 7, 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 partners 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 track tracking technology and LTE-V2X equipment and application server.

![Diagram of Vehicle-pedestrian Anti-collision](image)

**Figure 10.** Communication process of vehicle-pedestrian anti-collision

In this vehicle-pedestrian anti-collision solution, the pedestrian movement status information, coming from GPS, is transmitted to RSU through LTE network, and then RSU broadcasts the movement status information to vehicles at intersections. After receiving the information of pedestrian movement, the vehicle will make a decision based on collision avoidance algorithm, the buzzer and screen warning will be triggered if the pedestrian is in the area with collision risk.

4.3. 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 6 positioning base stations in the parking area of the industrial park, overall coverage of the parking area (320m * 50m) by positioning service based on 3.5GHz band signal is realized.

This solution achieved accurate positioning of 50 parking spaces. Through the statistics of dozens of positioning results for each parking space, the accuracy rate is more than 95%, i.e. the probability of less than plus or minus 1.4m error is more than 95% with the 2.8m width of parking space, which is able to meet the demand of parking space management in the industrial park of Wuhu Meizhi. In addition, the real-time track of the vehicle and the residence time record of the vehicle in the parking space were also carried out.

5. Conclusion

With the evolution of V2X services from assisted driving to automated driving, the use case requirements are also changing. According to the different requirements for V2X use cases, the positioning accuracies are also different. This paper introduces our study on requirements, architecture, key technologies and demonstrations in high accuracy positioning for V2X services. By combining the scene analysis and performance requirements, two system architectures for V2X high accuracy positioning is presented: device-centric positioning architecture and network-centric positioning architecture. In addition, the key technologies for high accuracy positioning of vehicles are proposed to provide the reliable location service. Finally, we demonstrate the proposal through a series of tests, including the evaluation of RTK systems based on cellular networks, vehicle-pedestrian anti-collision, parking management based on 5G high accuracy positioning and V2X application based on high-
precision positioning. Through these tests, we improve and evaluate the architecture and method of high accuracy positioning in different environments.

6. References

[1] 5GAA T-180156, "Considerations on high accuracy positioning for C-V2X", July 2018
[2] 3GPP TR 22.872, "Study on positioning use cases", March 2018
[3] Polvi J , Taketomi T , Yamamoto G , et al. SlidAR: A 3D positioning method for SLAM-based handheld augmented reality[J]. Computers & Graphics, 2016, 55:33-43
[4] Khattab A , Fahmy Y A , Abdel Wahab A . High Accuracy GPS-Free Vehicle Localization Framework via an INS-Assisted Single RSU[J]. International Journal of Distributed Sensor Networks, 2015, 2015:1-16.
[5] Kwon D , Ahn J , Chae D , et al. DCS-ctrl: A Fast and Flexible Device-Control Mechanism for Device-Centric Server Architecture[C]// Acm/ieee International Symposium on Computer Architecture. IEEE Computer Society, 2018
[6] Laso P M , Brosset D , Giraud M A . Secured Architecture for Unmanned Surface Vehicle Fleets Management and Control[C]// 2018 IEEE 16th Intl Conf on Dependable, Autonomic and Secure Computing, 16th Intl Conf on Pervasive Intelligence and Computing, 4th Intl Conf on Big Data Intelligence and Computing and Cyber Science and Technology Congress(DASC/PiCom/DataCom/CyberSciTech). IEEE, 2018
[7] Grineisen J , Rehme G . Evolution Path: The Telco-centric Digital Ecosystem: Successful Positioning of Network Operators in the Digital Age[M]/ Future Telco. 2019
[8] Bartonek D , Bures, Jií, Svabensky O . Optimization of Process Field Measurement GNSS-RTK for Railway Infrastructure[J]. Solid State Phenomena, 2016, 258:481-484
[9] 3GPP TSG-RAN WG1 Meeting #96, R1-1903022, GNSS-RTK and Hybrid Positioning for NG-RAN, March 2019
[10] 3GPP TSG-RAN WG1 Meeting #96, R1-1902549, TP on hybrid positioning and GNSS enhancements for TR 38.855, March 2019
[11] Chang Y M , Chu C P , Ma M Y . The Quantitative Analysis of Display Sizes and Positions of In-Vehicle Global Positioning System Sensor Systems[J]. Sensor Letters, 2014, 12(9):1433-1438.
[12] Bao J , Gu Y , Kamijo S . Vehicle positioning with the integration of scene understanding and 3D map in urban environment[C]// 2017 IEEE Intelligent Vehicles Symposium (IV). IEEE, 2017
[13] Giovanni N , Antonio V , Claudia C , et al. Cellular-V2X Communications for Platooning: Design and Evaluation[J]. Sensors, 2018, 18(5):1527-1535
[14] Guo X , Zhou Y , Wang J , et al. Precise point positioning for ground-based navigation systems without accurate time synchronization[J]. GPS Solutions, 2018, 22(2):34
[15] Biswash S K , Sarkar M , Sharma D K . Artificial immune system (AIS)-based location management scheme in mobile cellular networks[J]. Iran Journal of Computer Science, 2018, 1(4):227-236
[16] Libo C , Zheng C , Lingbo Y , et al. A Proposed Vision and Vehicle-to-infrastructure Communication Based Vehicle Positioning Approach[J]. Journal of Intelligent Transportation Systems, 2016