# Positioning and Sensing for Vehicular Safety Applications in 5G and Beyond

Citation for the original published paper (version of record):
Bartoletti, S., Wymeersch, H., Mach, T. et al (2021). Positioning and Sensing for Vehicular Safety Applications in 5G and Beyond. IEEE Communications Magazine, 59(11): 15-21.
http://dx.doi.org/10.1109/MCOM.011.2100339

# Positioning and Sensing for Vehicular Safety Applications in 5G and Beyond

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***Abstract*—This paper presents a shared vision among stakeholders across the value chain on the use of radio positioning and sensing for road safety in the 5G ecosystem. The key enabling technologies and architectural functionalities are explored, focusing on the extremely stringent localization and communication requirements. A case study for joint radar and communication using experimental data showcases the potential of the new enablers that are paving the way towards enhanced road safety in Beyond 5G scenarios.**

***Index Terms*—Vehicular, road safety, positioning, joint radar and communication, 5G.**

## I. INTRODUCTION AND MOTIVATION

The evolution of vehicular systems is moving towards ever more connected and fully automated vehicles. Such high level of autonomy leverages two main enablers, among others: local-awareness based on accurate positioning and sensing, and ultra-low latency communications among vehicles within a shared network infrastructure. These functionalities allow vehicles to develop a shared perception of their surroundings and make decisions based on local views and expected maneuvers from nearby users. The combination of ultra-low latency communication with accurate positioning and sensing leads the way towards a safer transportation system with the goal of achieving zero road deaths and a better traffic flow.

The 5G networks and devices have been enhanced with positioning functionalities since the Release 16 of the 3GPP (3rd Generation Partnership Project), thus elevating location information to a very important network service. 5G networks can operate in both sub-6 GHz and millimeter wave (mmWave) frequency bands and can employ massive antenna arrays, leading to large available bandwidth and accurate beamforming, as well as paving the way to new positioning methods such as multipath-assisted localization [1]. These features are expected to enable cm-level and degree-level accuracy of cellular localization in 5G and beyond [2]. Another key positioning technology that can provide cm-level positioning accuracy to outdoor vehicle user equipments (UEs) is the real time kinematics (RTK) global navigation satellite systems (GNSS), which is supported in 5G networks.

The enhancement of V2X (Vehicle-to-Everything) technology in 5G, which allows any vehicle to interact with any other road element (i.e., roadside units, pedestrians, network, and infrastructures) enables ultra-reliable low-latency communications (URLLC) with high data rates [3], [4]. Given such unprecedented combination of URLLC and high localization accuracy, 5G is the first technology that has the potential to meet the very stringent requirements of road safety applications. Nevertheless, several of the use cases presented by the industrial associations refer to extremely stringent latency and accuracy requirements, which might not be met by the 5G technology alone, especially in challenging operating conditions. In these scenarios, it is therefore necessary to employ advanced localization and sensing techniques, to hybridize with non-radio technologies, while remaining in accordance with the 5G architecture [5]–[8].

At the time when 5G is no longer a concept but a network generation being deployed and with a well-established standardized platform, this paper presents a unified vision of stakeholders across the value chain, including car industry, telecom equipment and user-device manufacturers, as well as leading academic institutions, on the use and evolution of 5G in road safety applications. We provide a comprehensive analysis of the performance requirements, enabling technologies in 5G and beyond, and main architectural functionalities that allow sensing and positioning data to be efficiently gathered, processed, and shared in the network. Finally, we present a case study for joint radar and communication, obtained with experimental data, to exemplify the new technical enablers and related challenges that open up the way for road safety in the Beyond 5G era.

## II. PERFORMANCE METRICS AND USE CASES

We now give an overview of the performance metrics that are critical for road safety applications and provide example use cases with stringent positioning-related requirements.

### A. *Safety-critical Performance Metrics*

The 5G system shall be able to provide positioning services according to the seven 3GPP positioning service levels defined in Release 17 [9]. Such service levels define the requirements in terms of several performance metrics. *Accuracy* has been the main target in the enhancement of positioning methods and architectures until now and is related to the estimation error for the absolute or relative position with respect to the true position. Relative positioning refers to the position estimation relatively to other network elements or to other UEs. Note that, while absolute positioning requires the UE to be in network coverage, (relative) sidelink measurements can be performed also out-of-coverage. Nevertheless, while sidelink communications in out-of-coverage have been already

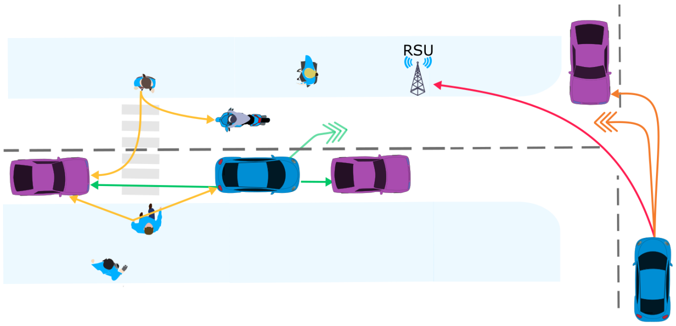

Fig. 1: Illustration of four use cases with stringent positioning requirements in an urban scenario: coordinated driving maneuver (green arrows), interactive VRU crossing (yellow), infrastructure assisted environment perception (magenta), and left turn in multi lane street with oncoming traffic (orange).

| Use Cases | Environment | Accuracy | Latency |
|---|---|---|---|
| Coordinated, Cooperative Driving maneuver | Urban, Rural, Highway, Intersection | 🟩 1.5m ($3\sigma$) | 🟩 160 ms |
| Interactive VRU Crossing | Urban | 🟨 0.2m ($3\sigma$) | 🟨 100 ms |
| Infrastructure Assisted Environment Perception | Urban, Highway, Intersection | 🟨 0.1 m ($3\sigma$) | 🟨 100 ms |
| Drifting out of lane | Urban, (Highway) | 🟨 0.08m ($1\sigma$) | 🟩 200 ms |
| Left turn in multilane street | Urban, Intersection | 🟨 0.13m ($1\sigma$) | 🟨 10 ms |

TABLE I: Example of safety-critical use cases and service level requirements. The reliability for all these use cases is 99.9%. According to the preliminary performance assessment from 3GPP [10], requirements in the green cells can be achieved under certain conditions, while the requirements in the yellow cells can generally not be achieved by the 3GPP Rel. 16.

standardized [3], the use of sidelink measurements for relative positioning is still under discussion. Among the seven service levels in [9], levels $1-6$ aim to provide absolute positions accuracy in the order of $0.3-10$ m depending on the scenario, whereas level 7 is the only one that targets relative position between two 5G devices.

Another key performance metric is the positioning service *latency* which is the time elapsed between the event that triggers the determination of the position-related data and the availability of the position-related data at the system interface [9]. The positioning service *availability* is the percentage amount of time the positioning service is operating within the performance requirements, divided by the expected value of such amount of time in the targeted service area. The service level requirements are defined also based on the environment where location-based service is offered (e.g., rural, urban) as the positioning performance change noticeably with different wireless propagation conditions and cellular network deployments. For example, in urban areas, due to obstructed wireless propagation and higher vehicle densities, the network deployment is much more critical than in rural areas, where even the RTK-GNSS technology is expected to provide decimeter-level accuracy in stand-alone configurations.

In parallel to those used for defining the positioning service levels, other metrics can represent additional requirements for the positioning system. For example, the *reliability* of a safety-critical service, i.e., how often positioning requests that satisfy requirements are successful, can be related to any degradation of the positioning accuracy. An additional performance metric, which depends jointly on accuracy, latency and reliability is the positioning *integrity*, which enables reliable navigation for the critical V2X and road safety applications. Positioning integrity, which is currently under discussion within 3GPP can be used to quantify the trust on the provided position, and therefore it is a method of bounding the errors with a much higher confidence.

### *B. C-V2X Use Cases*

The standardization of 5G-V2X is guided by advanced use cases that extend the basic applications defined in LTE-V2X. The 3GPP and the 5GAA (5G Automotive Association) are the two entities that have defined vehicular scenarios in 5G, by categorizing the use cases and indicating the key performance metrics. Fig. 1 illustrates multiple safety-critical use cases in a typical urban scenario. In particular, Table I summarizes the performance requirements of a few selected use cases with stringent requirements in terms of accuracy, latency, environment of use, and reliability for the use cases described in the following:

- *Coordinated, Cooperative Driving maneuver:* A vehicle shares its intention to perform a certain action (e.g., lane change) with other traffic participants potentially involved in the maneuver, which interact with the vehicle to confirm or decline the planned maneuver.
- *Interactive VRU Crossing:* A vulnerable road user (VRU), such as a pedestrian or cyclist, shares his or her intention to cross a road and interacts with vehicles approaching the area in order to improve safety for VRUs and awareness for vehicles.
- *Infrastructure Assisted Environment Perception:* A vehicle enters a section of the road that is covered by infrastructure sensors, e.g., roadside units (RSUs) and subscribes to receive the information from the infrastructure containing environment data from dynamic and static objects on the road.

We also find of interest two additional use cases defined by the Euro NCAP (European New Car Assessment Programme) Test Protocol for road traffic collision avoidance:

- *Drifting out of lane:* A sensing system detects a drift out of the lane and warns the driver or corrects the driving path autonomously before the ego car exits the lane.
- *Left turn in multi lane street with oncoming traffic* A vehicle performs a left turn across the path of the oncoming traffic.

The positioning service levels 4 and 6 defined in [9] for Rel. 17 are currently the closest to the requirements defined in Table I as they refer to 0.3 m of horizontal accuracy and latency of 15 and 10 ms, respectively. While the accuracy requirements in Table I refer to absolute positioning, there are many use

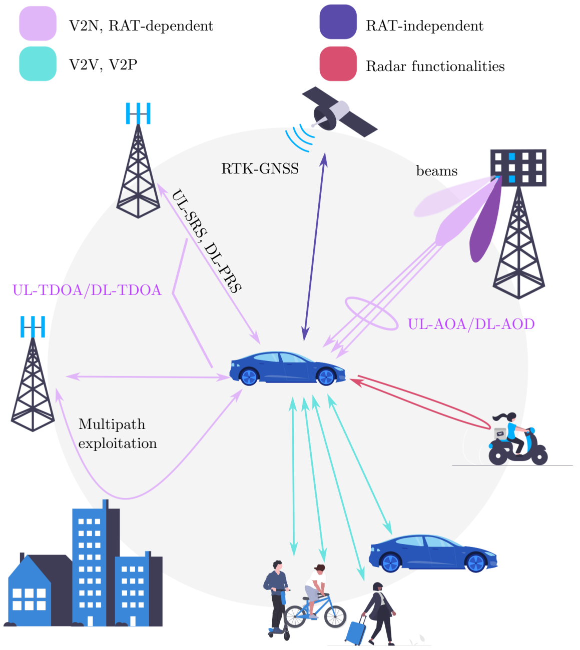

Fig. 2: Illustration of the different type of measurements between different road users for the positioning of the vehicle UE in the middle.

cases where relative positioning is more relevant (e.g., platooning and group start services). Therefore, relative positioning, accurate inter-vehicle ranging, and radar capabilities become the key functionalities in these safety-critical services, which operate under small inter-vehicle distances.

Furthermore, several of the use cases rely on localization, and in particular the positioning of the vehicle itself, but the VRU and environment perception use cases also include sensing aspects, where the shape and type of objects may need to be determined through passive (radar-like) measurements.

Ultimately, vehicular safety applications necessitate extreme positioning accuracy and latency. In real operating conditions, 5G technology alone is not always capable to meet these requirements, as visualized with colors in Table I. Indeed, preliminary studies conducted within the 3GPP [10] show that the horizontal positioning accuracy can achieve sub-meter levels in 90% of cases only in ideal conditions and that physical layer latency often exceeds 100 ms. Hence, progress is needed in terms of enhancing the existing 5G standard and in terms of new enabling technologies Beyond 5G.

## III. ENABLING TECHNOLOGIES IN 5G AND BEYOND

We now provide a brief overview of radio positioning in 5G vehicular scenarios, which is enabled by functionalities that are either dependent or independent on the radio access technology (RAT), as visualized in Fig. 2. Finally, we will discuss the main enablers of augmented localization accuracy in Beyond 5G scenarios and the emergence of joint communication, radio localization, and radar.

### *A. RAT-dependent Positioning*

The UE position in 5G is estimated based on location-dependent measurements (e.g., time of arrivals or angles) performed between the UE to be located and one or multiple gNBs [5]. Specifically, two signals have been defined for the purpose of UE positioning, namely downlink positioning reference signal (DL-PRS) and uplink sounding reference signal (UL-SRS). Nevertheless, it is possible to take advantage of other reference signals for positioning.

The position reference signals have a comb structure in time-frequency. This means that the signals use only a subset of available resources, but spread over the entire bandwidth, so that a high ranging resolution can be achieved, while allowing simultaneous transmission. The UE position is calculated by performing timing, angle, and power measurements of the received signals at the UE and/or gNBs (i.e., either uplink or downlink). In particular, time-difference-of-arrival (TDOA), angle-of-arrival (AOA), and angle-of-departure (AOD) measurements are taken at a single or multiple reception points. The TDOA is measured with respect to a reference base station. The angle measurements are obtained by measuring the received signal power from different beams pointing in distinct directions. The UE position is then computed leveraging on the combination of timing and angle measurements in the 5G core through the location management function (see the Architecture Section). As TDOA measurements are limited by synchronization between the involved gNBs, 5G has also introduced a multiple round-trip-time positioning method.

The combination of angle and timing measurements boosts the resolvability of the multipath, the latter being a major limitation to the achievable accuracy. In addition, the resolved multipath can be exploited through bistatic sensing to improve accuracy or reduce the need of infrastructure, leading to the possibility of positioning with even a single BS in a sufficiently rich environment.

For what concerns the latency performance, the major physical layer latency components for NR Positioning are (i) the reference signal alignment, transmission, measurement (including processing time), and report delay; (ii) the measurement gap request, configuration, and alignment time, as well as (iii) UE/gNB higher layer processing times. This broad group of components can cause delays in the end-to-end service. Therefore, current enhancements for the NR positioning involve signaling and protocols for a more efficient request and report of positional information.

The main RAT-dependent positioning support in 5G, including the positioning reference signals, measurements and methods were captured in 3GPP Release 16, while the basic positioning support for non-standalone NR was introduced in Release 15. Fig. 3 shows the roadmap of 3GPP standardization and highlights how the position-related performance metrics have been defined along the different releases, since LTE to the NR. Currently, the areas to be enhanced in terms of 5G positioning accuracy and latency improvements are being addressed in Release 17 work, by mitigating timing delays in different positioning solutions. Such positioning enhancements are addressed for industry applications in Rel. 17, whereas the investigation of V2X positioning enhancements has been deferred to later releases, possibly Rel. 18.

Aside from the standardization enhancements, we can consider several extensions of the RAT-based positioning methods.

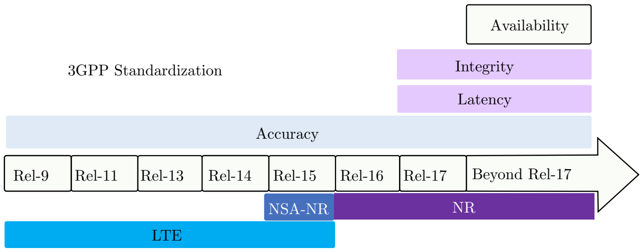

Fig. 3: Roadmap of the 3GPP standardization with the associated position-related performance metrics that have been defined in different releases (accuracy, latency, integrity, and availability).

For instance, the angular estimation does not need to be limited to the beam indices and corresponding received power, and can instead be based on the direct processing of the baseband waveform. This can considerably improve the AOA or AOD estimation accuracy. Moreover, by online adaptation of the beam codebook to the UEs locations, further improvements in accuracy and resolution can be achieved. Such spatial signal design provides a means to filter out interfering signal components and increases the received SNR. When the UE is also equipped with multiple antennas, it can also determine the AOA in its local frame of reference, thereby enabling orientation tracking by the UE.

### *B. RAT-independent Positioning*

The aim with RAT-independent positioning is to leverage the several radio interfaces in the UE that could be accessed and exploited for positioning. One main 5G RAT-independent technology for road-safety applications is the RTK-GNSS, which provides its assistance data via cellular networks using an open and inter-operable representation. The assistance data distribution can be via user plane or control plane or system information broadcast. The latter is the most scalable distribution form with many UEs within a region, which can be configured with assistance data encryption for authorization and user differentiation. The supported GNSS-RTK assistance data includes both observation space representation and state space representation including atmospheric delay models.

Sensor information is another RAT-independent technology supported in 5G and with a wide application in advanced driver assistance systems. The UE shares sensor data to the 3GPP location server, including displacement information (like bearing speed and distance travelled collected from inertial measurement unit, IMU), wheel sensors, steering wheel angle, and barometric sensors. The sensor information can enable the location server to estimate the UE trajectory between, after, or during the cellular positioning session, and can reduce the need of frequent measurements. The barometric sensors provide a valuable estimate of vertical position. This is also highly important for unmanned aerial vehicles and use-cases in which the vertical positioning accuracy becomes important.

3GPP standardization support for RTK-GNSS and IMU sensors occurred prior to 5G positioning support, back in Release 15, while the barometric sensor data was added much earlier in Release 13. In Release 17, the integrity positioning performance metrics are being supported for the GNSS positioning method. This support is fundamental for safe navigation as the user must trust her estimated position with a high degree of confidence. The positioning integrity performance metrics include: the *alert limit*, the largest allowable error for safe operation; the *time to alert*, the maximum allowable elapsed time from the onset of a positioning failure until the UE announces the alert; and the *target integrity risk*, the probability of providing a signal that is out of tolerance without warning the user in a given period of time.

### *C. Beyond 5G Positioning*

Although 5G technology represents a first tangible enabler for vehicle safety applications, as shown in Table I, extremely stringent latency and accuracy requirements might still not be reached in challenging operating conditions. As 5G systems evolve to Beyond 5G and 6G, new technical enablers will appear, in order to boost communication performance. The same enablers not only have implications for positioning performance but are expected to even rely on positioning for communication purposes. Hence, a tighter integration of communication and positioning is likely to occur. A non-exhaustive selection of such enablers includes the use of cell-free massive MIMO, wider bandwidths, new and even dedicated infrastructure, and finally the use of data-driven methods for system design and operation.

First of all, cell-free MIMO systems will have many more access points than users. In addition to reduced path loss and improved interference coordination for communication, this allows for many additional range measurements, increased effective aperture, and higher levels of integrity due to massive redundancy. Complementary to this development, a move to carriers up to 0.2 THz will open up massive bandwidths, leading to seemingly infinite capacity as well as cm-level ranging accuracy [2]. In addition, due to increased susceptibility to environmental factors, such THz signals have the potential for non-standard functionalities, such as pollution monitoring. Third, new infrastructure, in addition to conventional base stations, will improve positioning performance. These include not only cell-free access points, but also dedicated positioning infrastructure, as well as reconfigurable intelligent surfaces (RIS). Such RIS can be either active or passive, and provide a low-cost, low-energy solution to improve both communication and positioning coverage, through additional location references, automatic synchronization, and new observables (e.g., AOD from the RIS as well as wavefront curvature measurements). Finally, the presence of richer information provided by heterogeneous data increases the positioning accuracy, especially in challenging environments, yet requires important developments in algorithm design, driven largely by machine learning and artificial intelligence (AI). For example, the use of machine learning has been recently applied to the positioning problem with heterogeneous data [6].

### *D. Emerging Joint Communication, Positioning, and Sensing*

The vehicular safety use cases, such as those outlined by the 5GAA, have specific performance criteria in terms of absolute or relative positioning, as discussed in earlier sections. Many of these use cases (e.g. Interactive VRU, Cooperative maneuver) rely on the detection of other vehicles or obstacles using, for example, radar sensors. Therefore, the radar performance, e.g., in terms of range accuracy and Doppler resolution, becomes safety-critical. With enhanced resolution, multipath measurements from DL-PRS or UL-SRS can also be used for bistatic radar sensing, i.e., estimation of the positions of passive or unconnected devices and objects which reflect wireless signals. Even monostatic radar sensing is possible, provided the co-located transmitter and receiver can be sufficiently isolated for full-duplex operation. When these functionalities become part of future 3GPP standards, they will lead to the tight integration of communication, positioning, and radar, commonly referred to as joint radar and communication (JRC)) [11], [12]. With JRC, not just UEs but any object that is sensed wirelessly can be taken into consideration, which vastly amplifies the scope of use cases that can be addressed. This aids in meeting the requirements of vehicular safety applications, and can even be used to in turn improve UE positioning performance through better knowledge of the environment.

An experimental setup has been designed to showcase the ability of standard communication signals to provide monostatic radar measurements in line with the requirements from Table I. Specifically, we have performed measurements using orthogonal frequency-division multiplexing (OFDM) waveforms with random quadrature phase shift keying data symbols at 28 GHz and 60 GHz, with bandwidths 396 MHz and 1584 MHz, respectively (corresponding to data rates of approximately 100 Mbit/s and 400 Mbit/s) and a total duration of 4.16 ms. To distinguish targets in the presence of background reflections (e.g., from walls), we first obtain a reference measurement without an object and then collect measurements in the presence of an object at 4.2 m. Fig. 4 shows the range profiles with and without the object for OFDM waveforms, obtained by a co-located radar receiver via standard processing (i.e., after matched filtering in the frequency domain, we take an IFFT over the frequency domain to obtain the range profile) [12]. The example reported in Fig. 4 shows very high accuracy levels, whereas the Doppler resolution, even with larger bandwidth, might be insufficient to support novel safety-critical vehicular applications which may require Doppler resolutions down to 0.1 m/s. Therefore, it is important that the definition and standardization of new cellular systems beyond 5G will consider how the communication parameters affect JRC performance, and that the waveform design should take into account the radar performance requirements for vehicular safety scenarios.

## IV. ARCHITECTURE

The UE positioning in 5G can be carried out by the UE itself (network-assisted) or by the network (network-based). In RAT-independent positioning (e.g., GNSS/RTK-GNSS) the UE might localize itself without any aid from the network (standalone).

We now define the main architectural aspects enabling 5G location-based services. Then, we focus on the upper layer aspects of V2X communication.

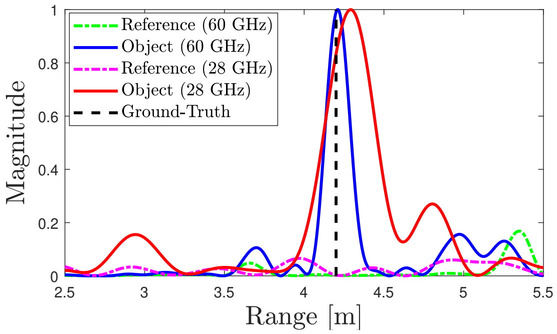

Fig. 4: Range profiles for OFDM waveforms obtained by monostatic sensing measurements at 28 GHz and 60 GHz in the presence of an object at 4.2 m. The ranging accuracies are around 10 cm and 1 cm while the Doppler resolutions are of 1.29 m/s and 0.60 m/s at 28 GHz and 60 GHz, respectively.

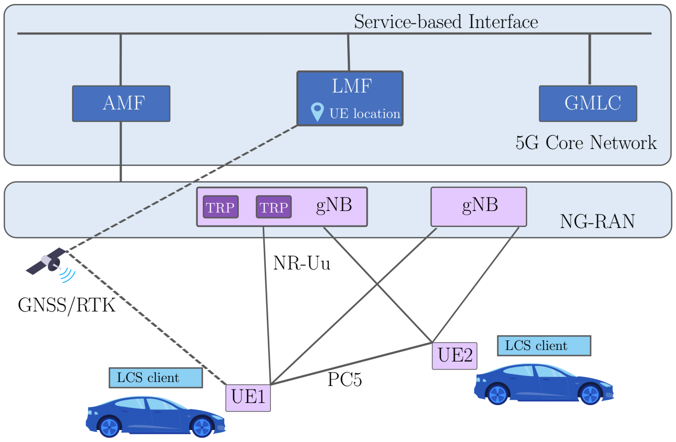

Fig. 5: Illustration of the main architecture elements enabling 5G vehicular positioning, in an example with two vehicle UEs and two gNBs with a single and multiple transmission reception points (TRPs).

### A. 5G Architecture

The 5G system consists of the next-generation radio access network and the 5G core network, as illustrated in Fig. 5. The 5G core network interacts with so called network functions through service-based interfaces.

Location-related functionalities for any UE, including vehicle UEs, are defined within the enhanced 3GPP Location Service architecture. A control plane location service is initiated by the access and mobility management function (AMF), either on behalf of a particular UE or after request from a location services client, i.e., the network element interacting with the gateway mobile location center (GMLC) to access and process location data. The client can be anywhere in the architecture, even inside the UE.

The location service request is then sent to the location management function (LMF), i.e., the location server, which coordinates and calculates the user position. In particular, the positioning assistance information and measurements are transferred between the UE and the TRPs to and from the LMF. The sensor information is also sent from UEs to LMF, and therefore in case of high density of UEs sharing information and requesting network-based positioning, the aforementioned LMF deployment strategy would be key to meet the demand and reducing the load on the network.

Positioning information from vehicle UEs can be shared through V2X communication. Existing network functions in the 5G core network have been extended in Release 16 with V2X related functionalities, defining two operation modes [3]: (i) sidelink V2X communications; and (ii) UL and DL transmissions. In case of positioning, the UE receives the required radio configuration information from the gNB via the latter interface. There is currently no support for sidelink positioning in the 3GPP standard.

### *B. Upper layers architecture based on ETSI ITS standard*

The ETSI Cooperative Intelligent Transport Systems (ETSI-ITS) supports road safety applications through different ITS services, which rely on the communication of dedicated messages exchanged between vehicles, infrastructure, or pedestrians. The main services to support road safety defined in the first two standard releases include [13]:

- *Cooperative Awareness Basic Service*, which allows road users and infrastructure to be informed about object state (e.g., vehicle time, position, activated systems) and attributes (e.g., dimension, type, role).
- *Decentralized Environmental Notification Basic Service*, which enables the communication of road hazards (e.g., icy road) or abnormal traffic conditions.
- *Vulnerable Road Users Awareness Basic Service*, which enables the operation of VRU awareness messages including position and other attributes for the protection of pedestrians, cyclists, motor cyclists and animals.
- *Collective Perception Service*, which enables to share the information about objects detected by local perception sensors (cameras, radars, etc.). Dedicated collective perception messages are under standardization.

Such services rely on V2X communication and leverage the architecture of ETSI-ITS protocol stack which includes: applications layer, facilities layer, networking and transport layer, access layer (which adopts 4G and 5G C-V2X requirements), management entity and security entity.

In the facilities layer, the ETSI ITS standard has defined the position and time (PoTi) services, specifying the functional architecture, exchanged messages, and protocols facilitating enhanced positioning and timing to support ITS applications [14]. The PoTi entity manages the position and time used by other ITS-S layers and leverages information from GNSS and other sensors (e.g., inertial, odometer, map matching) to manage kinematic and attitude state of the vehicle (i.e., time, position, and other motion information), as well as it maintains information about the confidence levels for such attitude state variables. PoTi supports various augmentation methods to improve the time and the location accuracy based on the external assistance data (e.g., RTK-GNSS or relative ranging between vehicles).

## V. OUTLOOK

Positioning solutions need to be flexible enough to address the dynamic requirements and complexity of vehicular safety applications. While 5G-NR goes a long way to meet the relevant use cases, a number of areas need to be addressed in the coming years:

- *Deployments:* Deployment and visibility of the anchor nodes critically affects the achievable positioning accuracy [7]. Algorithms for LOS detection, outlier rejection/suppression, or multipath exploitation are key for positioning performance. Other deployment strategies than those for data communication, i.e., with short distances between the reference points, may be needed to support vehicular safety applications [8], e.g., using multiple remote radio units, small cell deployments, or RIS [15].
- *Hardware:* When Beyond 5G systems operate at high carriers, hardware impairments will start to dominate positioning and sensing performance. These include power amplifier nonlinearity, mutual coupling, array calibration, and phase noise, which in turn will limit the available waveforms (e.g., OFDM may no longer be the best option), and the corresponding signal processing chain. At the same time, the availability of multiple radios operating at vastly different frequencies opens up the opportunity for multi-band localization and sensing.
- *Integrity, Security:* While GNSS-based integrity has been already standardized, the need for RAT-based integrity support is crucial for conditions such as urban canyon scenarios which lacks proper GNSS coverage. As the integrity is also associated to the trust on the user estimated position, location-security aspects will be critical in V2X scenarios. Indeed, a variety of adversaries are expected to find threatening value in attacking localization services in order to change the vehicle's location belief.
- *Methods:* Novel methods can exploit the multipath environment for positioning, making use of directional measurements from large antenna arrays, especially for mmWave deployments. Specific challenges arise in these scenarios, e.g., related to spatial coverage, hardware constraints, and antenna panel orientation. Positioning-optimized precoding of reference signals will need to be considered, as well as new processing methods for hardware-constrained waveforms, possibly using AI-based approaches. Finally, radio positioning system design should account for local GNSS coverage via novel sensor fusion approaches.
- *Architectures:* Network slicing has the service flexibility and security to enable new business models for positioning service providers and fulfilling critical V2X scenarios. Moreover, the large amount of data collected and the complexity of categorizing the users based on their requirements and capabilities of their network and environment demands the need for AI components together with edge cloud computing.
- *Automotive industry adoption:* Due to the complexity of the Cooperative ITS ecosystem and services, as well as the fact that V2X connectivity is just one of the technologies that may provide road sensing information on-board, it is still unclear the time-to-market for the technological developments outlined in this paper.

## ACKNOWLEDGEMENTS

This work was supported in part by the European Union's Horizon 2020 research and innovation programme under Grant no. 871249 (LOCUS project) and Sweden's Innovation Agency under Grant no. 2019-03085 (5GPOS project).

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