Top Level Newsletter: Connected Vehicle

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Vol 27: This issue features positioning and sensing technological trends related to autonomous vehicle technology.
(1) Positioning and Sensing for Vehicular Safety Applications in 5G and Beyond
(2) Letting Robocars See Around Corners: Using several bands of radar simultaneously can give autonomous vehicles a kind of second sight.

General Notes
This series of newsletters is intended to provide the IEEE member with a top level briefing of the many different subjects relevant to the research, development and innovation of the connected vehicle.

The objective is to provide a platform for fast learning and quick overview so that the reader may be guided to the next levels of detail and gain insight into correlations between the entries to enable growth of the technology. Intended audiences are those that desire a quick introduction to the subject and who may wish to take it further and deepen their knowledge. This includes those in industry, academia or government and the public at large. Descriptions will include a range of flavors from technical detail to broad industry and administrative issues. A (soft) limit of 300 to 600 words is usually set for each entry, but not rigorously exercised.

As descriptions are not exhaustive, hyperlinks are occasionally provided to give the reader a first means of delving into the next level of detail. The reader is encouraged to develop a first level understanding of the topic in view. The emphasis is on brief, clear and contained text. There will be no diagrams in order to keep the publication concise and podcast-friendly. Related topics in the case of Connected Vehicle technology, such as 5G cellular and the Internet of Things will be included. The terms Connected Vehicle and Automated Driving will be used inter-changeably. Articles from other published sources than IEEE that add to the information value will occasionally be included.

This newsletter forms part of the regional Advanced Technology Initiative (ATI) of which connected vehicles form a constituent part. Technical articles solely from IEEE journals/magazines are referred to by their Digital Object Identifier (DOI) or corresponding https link. The link for each article is provided. Those readers who wish to delve further to the complete paper and have access to IEEE Explore (www.ieeexplore.ieee.org) may download complete articles of interest. Those who subscribe to the relevant IEEE society and receive the journal may already have physical or electronic copies. In case of difficulty please contact the editor at kaydas@mac.com. The objective is to provide *top level guidance* on the subject of interest. As this is a collection of summaries of already published articles and serves to further widen audiences for the benefit of each publication, no copyright issues are foreseen.

Readers are encouraged to develop their own onward sources of information, discover and draw inferences, join the dots, and further develop the technology. Entries in the newsletter are normally either editorials or summaries or abstracts of articles. Where a deepening of knowledge is desired, reading the full article is recommended.

1.Positioning and Sensing for Vehicular Safety Applications in 5G and Beyond, Stefania Bartoletti et al.

Published: IEEE Communications Magazine (Vol 59, Issue 11, November, pp 15-27)

Introduction and Motivation: The evolution of vehicular systems is moving toward ever more connected and fully automated vehicles. Such a 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 ultralow latency communication with accurate positioning and sensing leads the way toward a safer transportation system. with better traffic flow.

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. These features are expected to enable centimeter level and degree level accuracy of cellular localization in 5G and beyond. Another key positioning technology that can provide centimeter level positioning accuracy to outdoor vehicle user equipments (UEs) is the real-time kinematics (RTK) global navigation satellite system (GNSS), which is supported in 5G networks**.**

The enhancement of vehicle-to-everything (V2X) 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. Given the 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 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, and to hybridize with non-radio technologies, while remaining in accordance with the 5G architecture.

At a time when 5G is no longer a concept but a network generation being deployed and with a well-established standardized platform, this article presents a unified vision of stakeholders across the value chain, including automotive industry, telecom equipment, and user device manufacturers, as well as leading academic institutions, on the use and evolution of 5G in road safety applications.

ENABLING TECHNOLOGIES in 5G AND BEYOND: We provide a brief overview of radio positioning in 5G vehicular scenarios, which is enabled by functionalities that are either dependent on or independent of the radio access technology (RAT).

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 next generation Node Bs (gNBs). 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 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 the combination of timing and angle measurements in the 5G core through the location management function.

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 for infrastructure, leading to the possibility of positioning with even a single BS in a sufficiently rich environment.

RAT-Independent Positioning: The aim of 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.

Beyond 5G Positioning: Although 5G technology represents a first tangible enabler for vehicle safety applications, 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 multiple-input multiple-output (MIMO), wider bandwidths, new and even dedicated infrastructure, and finally, the use of data-driven methods for system design and operation.

OUTLOOK:

Positioning solutions need to be flexible enough to address the dynamic requirements and complexity of vehicular safety applications. While 5G-New Radio 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. Algorithms for Line of Sight detection, outlier rejection/suppression, and multipath exploitation are key for positioning performance**.**

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 multiband 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 that lack proper GNSS coverage. As the integrity is also associated with the trust in the user-estimated position, location security aspects will be critical in V2X scenarios.

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 the capabilities of their network and environment demands AI components together with edge cloud computing**.**

Automotive Industry Adoption: Due to the complexity of the cooperative Intelligent Transport System (ITS) ecosystem and services, as well as the fact that V2X connectivity is just one of the technologies that may provide road sensing information onboard, the time to market for the technological developments outlined in this article is still unclear. (1213 words)

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2. Letting (Robo) Cars See Around Corners, Behrooz Rezwani et al

Published: IEEE Spectrum Magazine (Vol 59, Issue 2, February 2022, pp 36-41)

An autonomous car needs to do many things to make the grade, but without a doubt, sensing and understanding its environment are the most critical. A self-driving vehicle must track and identify many objects and targets, whether they're in clear view or hidden, whether the weather is fair or foul.

Today's radar alone is nowhere near good enough to handle the entire job–cameras and lidars are also needed. But if we could make the most of radar's particular strengths, we might dispense with at least some of those supplementary sensors.

Conventional cameras in stereo mode can indeed detect objects, gauge their distance, and estimate their speeds, but they don't have the accuracy required for fully autonomous driving. In addition, cameras do not work well at night, in fog, or in direct sunlight, and systems that use them are prone to being fooled by optical illusions. Laser scanning systems, or lidars, do supply their own illumination and thus are often superior to cameras in bad weather. Nonetheless, they can see only straight ahead, along a clear line of sight, and will therefore not be able to detect a car approaching an intersection while hiddenfrom view by buildings or other obstacles.

Radar is worse than lidar in range accuracy and angular resolution—the smallest angle of arrival between two distinct targets that's needed to resolve one from another. But we have devised a novel radar architecture that overcomes these deficiencies, making it much more effective in augmenting lidars and cameras.

Our proposed architecture employs what's called a sparse, wide-aperture multiband radar. The basic idea is to use a variety of frequencies, exploiting the particular properties of each one, to free the system from the vicissitudes of the weather and to see through and around corners. That system, in turn, employs advanced signal processing and sensor-fusion algorithms to produce an integrated representation of the environment.

Each frequency band has its strengths and weaknesses. The band at 77 giga-hertz and below can pass through 1,000 meters of dense fog without losing more than a fraction of a decibel of signal strength. Contrast that with lidars and cameras, which lose 10 to 15 decibels in just 50 meters of such fog.

Rain, however, is another story. Even light showers will attenuate 77-GHz radar as much as they would lidar. No problem, you might think—just go to lower frequencies. Rain is, after all, transparent to radar at, say, 1 GHz or below.

This works, but you want the high bands as well, because the low bands provide poorer range and angular resolution. Although you can't necessarily equate high frequency with a narrow beam, you can use an antenna array, or highly directive antenna, to project the millimeter-long waves in the higher bands in a narrow beam, like a laser. This means that this radar can compete with lidar systems, although it would still suffer from the same inability to see outside a line of sight.

One weakness of radar is that it follows many paths, bouncing off innumerable objects, on its way to and from the object being tracked. These radar returns are further complicated by the presence of many other automotive radars on the road. But the tangle also brings a strength: The widely ranging ricochets can provide a computer with information about what's going on in places that a beam projected along the line of sight can't reach—for instance, revealing cross traffic that is obscured from direct detection.

Seeing around the corner can be depicted easily in simulations. We considered an autonomous vehicle, equipped with our system, approaching an urban intersection with four high-rise concrete buildings, one at each corner. At the beginning of the simulation the vehicle is 35 meters from the center of the intersection and a second vehicle is approaching the center via a crossing road. The approaching vehicle is not within the autonomous vehicle's line of sight and so cannot be detected without a means of seeing around the corner.

As the autonomous vehicle and the various targets move and as more data is collected by the radar, each new piece of evidence is used to update the probabilities. This is Bayesian logic, familiar from its use in medical diagnosis. Does the patient have a fever? If so, is there a rash? Here, each time the car's system updates the estimate, it narrows the range of possibilities until at last the true target positions are revealed and the “ghost targets” vanish. The performance of the system can be significantly enhanced by fusing information obtained from multiple bands.

We have used experiments and numerical simulations to evaluate the theoretical performance limits of our radar system under various operating conditions. Road tests confirm that the radar can detect signals coming through occlusions. In the coming months we plan to demonstrate round-the-corner sensing. We expect that these features will enable a form of driving safer than we have ever known. (820 words)

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