NOKIA Bell Labs

The evolution of 5G New Radio positioning technologies

White paper

The evolution of 5G New Radio (NR) shows that positioning services are becoming important components of current and future cellular networks. From providing emergency services with device locations to tracking automated forklifts on a factory floor, the use cases for 5G NR technology continue to be enhanced through the release of 3GPP specifications. Horizontal and vertical accuracy is an important focus in Releases 16 through 18, with latency and reliability becoming important for many Industrial Internet of Things (IIoT) use cases in the future.

This paper looks at a wide diversity of anticipated use cases and scenarios, and the technology features expected to be introduced to meet the positioning requirements. While Release 16 already introduced six radio access technology (RAT)-dependent techniques to enable precise positioning, Release 17 will continue to work on improved accuracy, lower latency, positioning integrity, and device and network efficiency. Further enhancements and expansions of NR positioning will take place with positioning and location awareness as core features of future releases of the specifications.

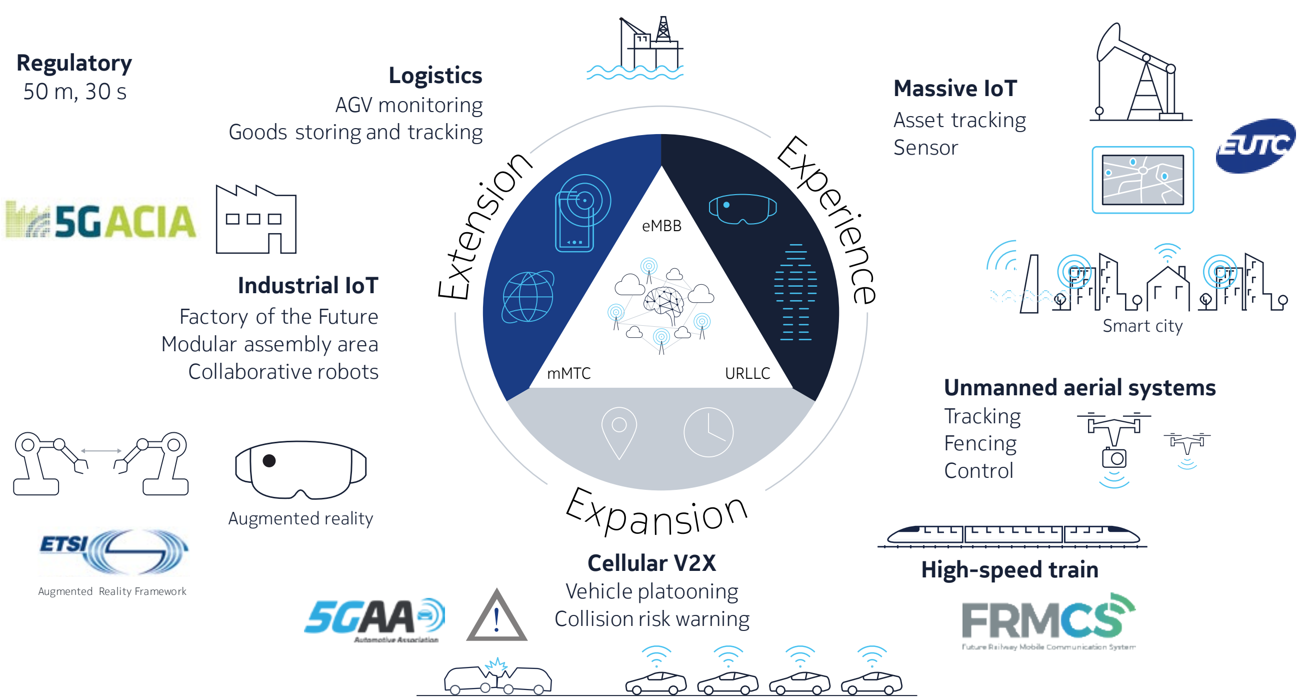
Contents

Introduction

Positioning (aka localization) technology utilizing 3G, 4G and Wi-Fi systems has existed for at least the last 20 years. 5G New Radio (NR) Positioning is now evolving as a key feature that enables the operator of a 5G network to position devices for both indoor and outdoor applications with much better accuracy and reliability than those of previous generations.

A wide variety of use cases require positioning services—from locating emergency callers' locations to autonomous driving to tracking automated forklifts moving in a factory. Many of these use cases, which will expand the applicability of 5G networks beyond traditional mobile broadband, require accurate positioning in order to function. 5G networks offer the exciting possibility to deploy a single technology that addresses both the positioning and data needs of these use cases in an integrated solution, all in an ultra-reliable manner.

Figure 1. Positioning use cases examples



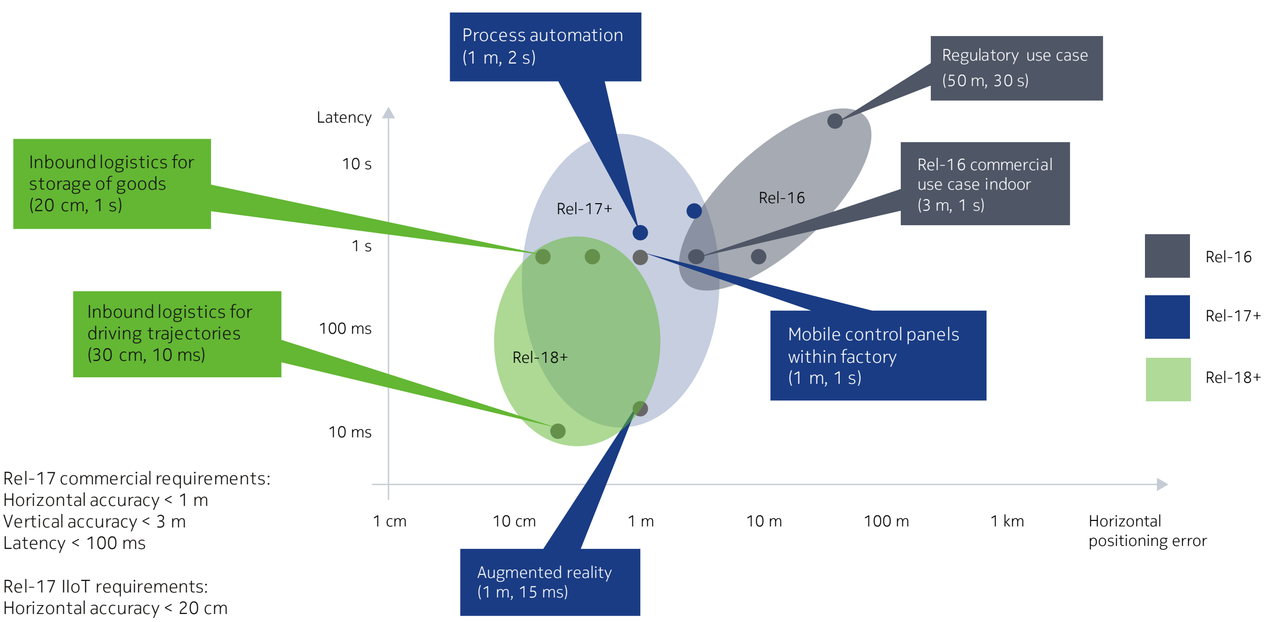
So far 5G-based positioning relies on timing-based, angle-based, power-based or hybrid techniques to locate users. Improved positioning accuracies can be achieved with 5G technologies by taking advantage of the wide bandwidth signals in NR, beamforming capabilities that come from the large number of antenna elements in massive multiple-input, multiple output (MIMO) networks, and the denser 5G network deployments.

Positioning using 5G can complement or act as an alternative to traditional global navigation satellite system (GNSS)-based positioning in many use cases where GNSS coverage is not available (e.g., indoor or dense urban areas). 5G positioning can also be fused with GNSS positioning to improve accuracy, and 5G networks can be used to deliver assistance data in high-accuracy GNSS techniques.

Use cases and requirements

With 5G positioning in a diverse set of use cases comes a diverse set of requirements. Figure 2 shows the evolving requirements as they map to 3GPP Releases. The two key metrics that we focus on here are the latency and horizontal positioning error, but these are certainly not the only metrics. For regulatory use cases, the accuracies required are in the order of tens of meters, while for additional Release 16 (Rel-16) commercial use cases, horizontal accuracies of less than 10 meters for 80% of users in outdoor applications were required. The targeted performance in Rel-17 for Industrial Internet of Things (IIoT) use cases is 20 centimeters horizontal positioning accuracy and less than 1 meter vertical accuracy for 90% of devices.

Figure 2. Positioning requirements across various 3GPP Releases



Rel-17 commercial requirements:
Horizontal accuracy < 1 m
Vertical accuracy < 3 m
Latency < 100 ms

Rel-17 IIoT requirements:
Horizontal accuracy < 20 cm
Vertical accuracy < 1 m
Latency < order of 10 ms desired

Source: TR 38.857

Along with accuracy, latency is an important requirement; for mobile users, high accuracy is not useful if the estimation is of a past location far from the current location. Regulatory use cases only required latencies less than 30 seconds but latencies down to 10 milliseconds are needed for some IIoT use cases such as tracking driving trajectories on a factory floor.

In addition to accuracy and latency, the coverage area of the localization service is an important characteristic. Unlike Wi-Fi, which only provides limited indoor coverage for the localization service—or GNSS, which is restricted to outdoor applications—5G offers a continuous localization service indoors and outdoors across a wide area network. The accuracy, which depends on the density of radios, can vary across the wide area coverage, e.g., high precision for indoor localization with a high density of radio access points, and coarse precision in the outdoors with a lower density of base stations.

Tools in the toolbox – Release 16 5G NR

During Rel-15, some basic positioning features were introduced to NR that covered the non-standalone deployment case (e.g., using LTE carriers for positioning) and RAT-independent deployment (i.e., non-NR-based methods such as GNSS or Wi-Fi). The wide variety of use cases (e.g., indoor and outdoor), deployment scenarios (e.g., mmWave and sub-6 GHz), and positioning requirements that are covered by 5G led to a diverse set of RAT-dependent techniques being introduced in Rel-16 NR.

The RAT-dependent techniques in NR can be thought of as adding tools to the NR toolbox, which can be used to meet positioning requirements in different use cases and scenarios. In Rel-16, six different RAT-dependent techniques were introduced:

- NR Enhanced cell ID (E-CID)
- Downlink time difference of arrival (DL-TDOA)
- Uplink time difference of arrival (UL-TDOA)
- Downlink Angle of departure (DL-AoD)
- Uplink Angle of arrival (UL AoA)
- Multi-cell round trip time (multi-RTT).

These techniques rely on time, angle and power measurements at either the device side, the network side or a combination of multiple measurements. Some of the methods (e.g., DL-AoD) were introduced to take advantage of the beamforming capabilities of NR and may be better suited for mmWave deployments. Other techniques such as multi-RTT were introduced, based on learning from LTE to address positioning errors caused by synchronization offsets between base stations.

Similar to LTE, NR supports network-based positioning where the measurements are reported by the base stations and/or the users to a central location server, which then computes the position estimate. In addition, in NR, UE-based positioning was introduced for downlink techniques; this is where the user calculates the position estimate based on the self-conducted measurements in conjunction with base station locations, which are provided to the user by the network.

Refining the tools for the Industrial IoT – Release 17

Beyond the emergency call use case, which was the focus of Rel-16, NR positioning is an exciting feature for many future network applications. Many of the most promising (and demanding) use cases are related to the IIoT. To address these use cases in indoor factories, enhancements to the Rel-16 NR positioning solutions are currently being developed by 3GPP. The full scope of the enhancements is still open, but specification work is likely to be done in the following areas:

- Improved accuracy: Sharpening the tools available in Rel-16 to improve the achievable accuracy is underway, potentially including non-line-of-sight identification and mitigation as well as positioning using carrier aggregation.
- Latency reductions: Enhancements to the signaling and procedures are under discussion to meet the latency requirements of at most 100 milliseconds.
- Positioning integrity: Positioning integrity refers to the level of trust associated with the positioning information.
- Scalable and efficient solutions: Rel-17 will support users in an inactive state performing positioning. This enhancement improves the device and network efficiency while allowing networks to scale to larger numbers of users being positioned simultaneously.

Nokia is currently enabling the ARENA2036, which is an experimental future factory to trial innovations for industrial automation with industry partners—working with cutting edge 5G technology, edge cloud and high-speed optical data transmission with an emphasis on precise terrestrial positioning deployed indoors. Nokia is leveraging the realistic industrial testbed of ARENA2036 to evaluate its Rel-17 NR positioning solution. Tracking of materials, products, and the production environment itself is critical to enabling the Fourth Industrial Revolution.

Release 18 and beyond

Beyond Rel-17, and even as 6G takes shape, it is very likely that even further enhancements and expansions of NR positioning will be developed, and positioning and location awareness will be a core feature of these future networks. Releases 16 and 17 have enabled an exciting baseline of solutions that will continue to be improved to address the expanding 5G ecosystem. While it is too early to know which use cases will be addressed in which 3GPP Release, 5G NR may be making enhancements in a few other exciting areas such as:

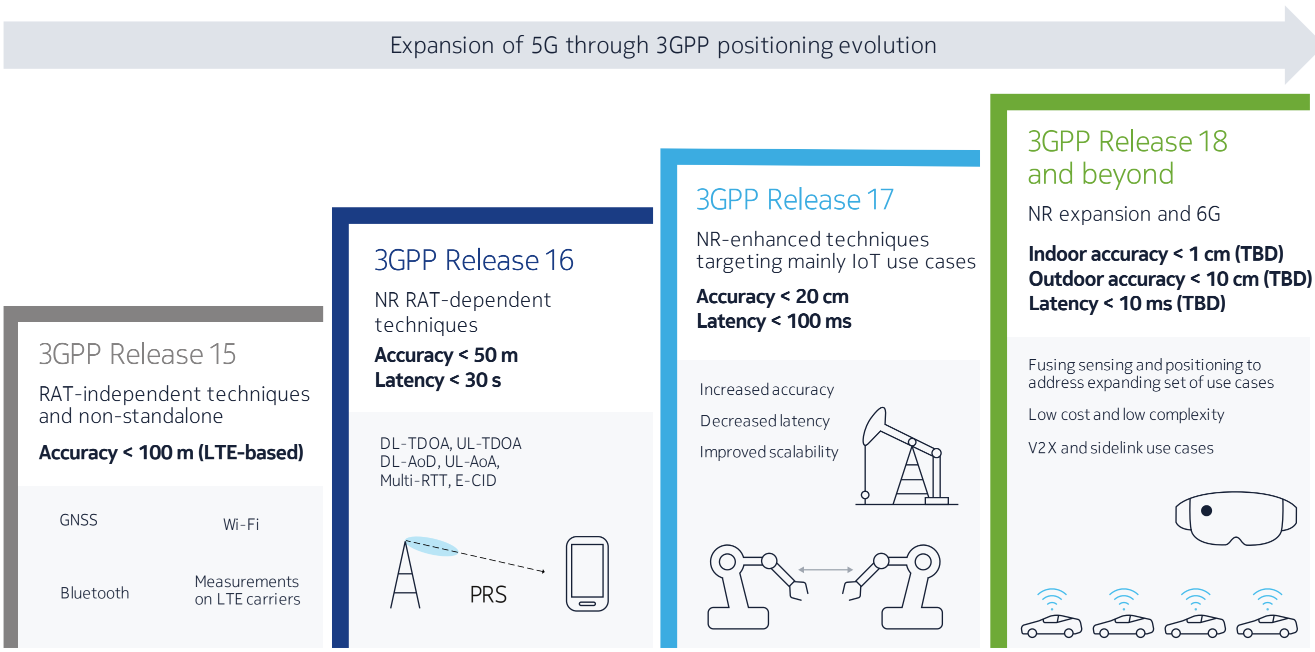
- Carrier-phase-based positioning, which promises higher accuracy
- Positioning using unlicensed spectrum (e.g., NR-U-based positioning)
- Very-low-cost and low-complexity positioning to enable asset tracking
- Sidelink and V2X positioning to address use cases like autonomous driving
- Positioning and pose estimation for extended reality applications.

Even beyond the above enhancements, we envision that 6G networks will have sensing capabilities that will enable the coexistence of communications, positioning and sensing over one network and unlock many more use cases. Moreover, 6G is anticipated to incorporate machine learning solutions in positioning, such that the location coordinates, or relevant parameters, are estimated as an outcome of a process where traditional methods are supplemented with artificial intelligence.

Summary

Positioning of devices has a wide diversity of use cases in current and future cellular network deployments. 5G NR has already addressed many of these uses cases in Rel-15 and Rel-16, while further enhancements are still underway in Rel-17. Use cases range from providing emergency services with device locations to moving robots in IIoT factories of the future. As 5G NR continues to evolve and change the world around us, it is clear that positioning services are a necessary and seamless component of cellular networks that will only continue to expand the ways in which 5G and eventually 6G can be deployed.

Figure 3. Positioning features for 3GPP Rel-15 to Rel-18 and beyond



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Abbreviations

DL-AoD	downlink angle of departure
DL-TDOA	downlink time difference of arrival
E-CID	enhanced cell ID
eMBB	enhanced mobile broadband
GNSS	global navigation satellite system
IIoT	Industrial Internet of Things
MIMO	multiple-input, multiple-output
mMTC	massive machine-type communications
NR	New Radio
RAT	radio access technology
RTT	round trip time
UE	user equipment
UL-TDOA	uplink time difference of arrival
URLLC	ultra reliable low-latency communications
V2X	vehicle to everything

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