Chao Yang and Shiwen Mao *Dept. Electrical & Computer Engineering, Auburn University, Auburn, AL* **Xuyu Wang** *Dept. Computer Science, California State University, Sacramento, CA*

Editors: Shiwen Mao and Michelle Gong

Photo, istockphoto.com

AN OVERVIEW OF 3GPP POSITIONING STANDARDS

With the growing demand for locating services in a variety of commercial applications, positioning techniques have been considered as a vital part in cellular networks. With the evolution from 2G to 5G, the positioning techniques have been enhanced in various aspects. In this paper, we summarize the evolution of positioning standards in the Third Generation Partnership Project (3GPP) and briefly introduce the new positioning standards in 5G NR (New Radio), which include new positioning requirements, the general positioning structure, new positioning reference signals, and general positioning methods.

Positioning service in cellular networks was first developed in the Global System in Mobile Communications (GSM) network, aiming to provide the location of emergency calls [1]. The order was issued by the US Federal Communication Commission (FCC) in 1996, requiring wireless operators to report emergency calls to the nearby Public Safety Answering Point (PSAP). In the beginning, the positioning support only covered outdoor emergency calls. However, with the increasing number of indoor calls, the positioning support was required to be extended to the indoor scenario. Indoor positioning requirement was firstly considered and studied in Rel.13 and Rel.14 of 3GPP specifications.

With the rapid development of cellular radio access network (RANs), positioning of user equipment (UE) was further extended to support other commercial applications, such as billing service, marketing, entertainment, health care, and social networks [2]. Furthermore, vehicle-to-everything (V2X) based on LTE has been developed to offer effective communication services for vehicles, which also requires real-time and accurate vehicle locations [3]. The requirements on the positioning service also evolve from location accuracy to the confidence level and positioning latency.

In this article, we examine how the cellular positioning standards evolved with increasing requirements from 2G to 5G. As the development of commercial applications in the past decades, more restricted positioning requirements are considered in the new generation of 5G NR. We introduce the new positioning requirements considered in 3GPP standards for 5G NR, as well as the possible approaches to satisfy these requirements. The 3GPP defines a new positioning service architecture for 5G NR, which is also compatible with the current LTE service. Furthermore, we introduce the new 5G positioning signals proposed to further enhance the positioning performance, along with new positioning methods. In the remainder of this article, we will first review the evolution of positioning service in cellular networks. We will then introduce the most advanced positioning standards for 5G NR in various aspects. The new requirements will be introduced next, along with the general positioning architecture. The proposed new positioning reference signals and general positioning methods will be described next. Finally, we present the conclusions.

TABLE 1. Evolution of Positioning Methods and Protocols in 3GPP Standards.

Cellular Technology	GERAN	UMTS	LTE	5G NR
General Positioning Methods	E-CID, EOTD, UTDOA, GNSS	E-CID, UTDOA, GNSS, AoA, OTDOA-IPDL	E-CID, OTDOA, AoA, A-GNSS	NR E-CID, Multi-RTT, UL-TDOA, UL-AoA, DL-TDOA, DL-AoD
Positioning Protocols	RRLP	RRC	LPP	NRPPa, LPP

TABLE 2. NR Positioning Requirements for Commercial Use Cases

Positioning Cases	Horizontal Error	Vertical Error	End to End Latency
Indoor Scenarios	<3m for 80% UEs	<3m for 80% UEs	< 1s
Outdoor Scenarios	<10m for 80% UEs	<3m for 80% UEs	< 1s

EVOLUTION OF 3GPP POSITIONING STANDARDS

Positioning is a vital part of cellular networks. We review the evolution of positioning techniques in different cellular network generations [2, 4] from two aspects: General positioning methods and positioning protocols, as summarized in Table 1.

Positioning service was first introduced in GSM/GPRS/EDGE RAN (GERAN). Several typical positioning methods were incorporated to support location service (LCS) in 2G networks, such as Enhanced Cell Identity (E-CID), Enhanced Observed Time Difference (EOTD), Uplink Time Difference of Arrival (UTDOA), and Global Navigation Satellite System (GNSS). Based on the measurement algorithm, these positioning techniques can be classified into three categories: centroid-based methods (E-CID), hyperbolic multilateration positioning methods (EOTD, UTDOA), and GPS-based methods (GNSS) [2]. The specific LCS protocol used in GERAN is Radio Resource LCS Protocol (RRLP), which is responsible for the three procedures in LCS, including positioning measurement, assistance data delivery, and error handling.

Some of these positioning methods were further enhanced in the 3G cellular networks (i.e., the Universal Mobile Telecommunications System (UMTS)). For example, the round-trip time (RTT) parameter was introduced in E-CID to improve the positioning accuracy. Moreover, Observed Time Difference of Arrival with Idle Period in the Downlink (OTDOA-IPDL) was proposed to replace EOTD, which was adapted to the Wideband Code Division Multiple Access (WCDMA) in UMTS networks. The Angle of Arrival (AoA) positioning method was proposed to implement antenna array-based localization in Node B. The positioning protocol used in UMTS is embedded in Radio Resource Control (RCC) [5], which is a network layer protocol. In UMTS and the following generation networks, RCC not only supports

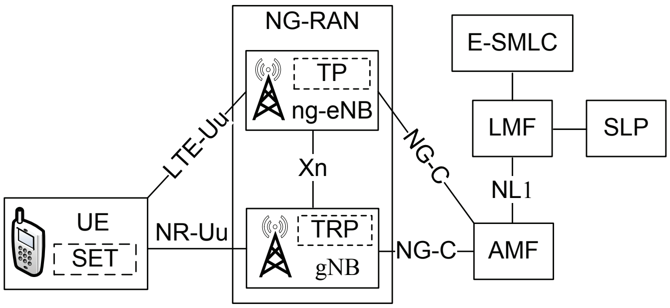

FIGURE 1. The general architecture of UE positioning in 5G NR.

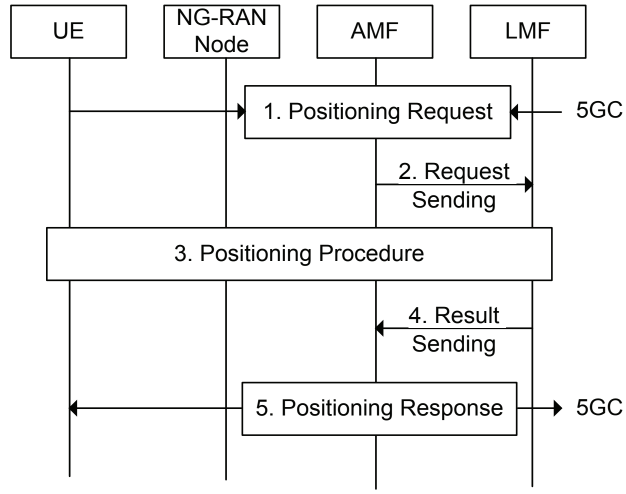

FIGURE 2. The general location service procedure in 5G NR.

positioning related data transmissions but also supports other functions, such as power control and paging notification.

Following GERAN and UMTS, the Long-Term Evolution (LTE) network incorporated more advanced positioning techniques. For instance, Assisted GNSS (A-GNSS) is an enhanced GNSS positioning method that also supports the Russian GLONASS and future constellations. With multiple constellations supported, A-GNSS is capable of achieving more precise outdoor positioning than the traditional GNSS. In addition, the accuracy of E-CID and OTDOA has been enhanced by using more reference data (i.e., received signal strength (RSS) and position reference signal (PRS)). A hybrid positioning method was also developed in LTE to combine the positioning results from multiple techniques. The localization protocol in LTE is the LTE positioning protocol (LPP) [6], which is designed both for LTE and for future LCS applications.

In the following generation, i.e., 5G NR, the positioning technologies have further evolved by introducing 5G specific positioning reference signals and positioning methods. Many positioning methods have been proposed to support advanced positioning services, so Table 1 is by no means a complete list. We only list the Radio Access Technology (RAT)-dependent positioning methods in 5G, such as Multi-RTT, UL-TDOA, UL-AoA, DL-TDOA, and Downlink angle-of-departure (DL-AoD). The 5G positioning protocols have also been developed based on LTE, including NR Positioning Protocol A (NRPPa) and LPP. We will elaborate on these new 5G positioning techniques later in this article.

In conclusion, the evolution of the positioning service in 3GPP standards shows that new positioning requirements of LCS are emerging over the years. The improved poisoning accuracy has been mostly achieved by incorporating more effective position reference signals and more advanced positioning techniques.

WITH THE EVOLUTION FROM 2G TO 5G, THE POSITIONING TECHNIQUES HAVE BEEN ENHANCED IN VARIOUS ASPECTS

NEW POSITIONING REQUIREMENTS IN 5G NR

For 5G NR, 3GPP releases the requirement of LCS for the next generation network in Release-16 [7]. The improvement of the LCS in the next generation network is significant and multidimensional, which includes supported range, positioning accuracy, network complexity, latency, cost, compatibility, power consumption, availability, and compatibility for hybrid techniques. Based on these enhancement goals, the positioning requirements are determined in 3GPP Re-16 [9].

For regulatory use cases in 5G, 3GPP determines that the minimum horizontal positioning error should be less than 50m for 80% of UEs, while the vertical positioning error should be smaller than 5m. The end-to-end latency should be less than 30s. However, when it comes to commercial use cases, the positioning requirements are determined much more rigidly, which considers both indoor and outdoor scenarios. As Table 2 shows, the latency of LCS should be reduced to less than 1s. The vertical localization error should be less than 3m for both indoor and outdoor positioning scenarios. In contrast, the horizontal error requirements for the two scenarios are different. In the large-space outdoor positioning scenarios, the horizontal measurement error should be within 10m, while the positioning error for indoor cases should be under 3m.

To meet these requirements, 5G NR positioning design should exploit the specific benefits of the 5G network, such as the high bandwidth, the massive deployment of gNBs (or gNodeB, NR base station) and the antenna arrays utilized in massive MIMO systems. A design leveraging the high bandwidth (above 6GHz) could substantially improve the accuracy bounds of traditional positioning methods, such as TDOA and E-CID. Furthermore, the massive antenna array used in 5G networks introduces an additional degree of freedom (DoF) in the spatial domain of the wireless channel, which has a great potential to significantly improve the localization performance. Incorporating both RAT-dependent and RAT-independent positioning techniques is also an effective approach to achieve high positioning accuracy in various scenarios.

GENERAL POSITIONING ARCHITECTURE AND PROCEDURE

The architecture of 5G positioning has evolved from the positioning architecture used in LTE [4]. Thus, the positioning in 5G is also compatible with the positioning methods proposed in 4G. Figure 1 illustrates the general architecture of UE positioning for Next Generation Radio Access Network (NG-RAN) [10]. As the figure shows, the positioning procedure is composed of four components, including the UE, NG-RAN, Access and Mobility Management Function (AMF), and Location Management Function (LMF).

1. Main Components in 5G Positioning

The core module of LCS in 5G is the LMF, which manages the support of various positioning services. During the UE positioning process, the LMF first identifies the positioning methods and invokes the positioning tasks in the UEs and the related base stations in the NG-RAN. Then, the LMF collects the positioning measurements from the corresponding terminals and determines a final position estimation result for LCS. However, the LMF itself could not generate the positioning reference data; all the position data is collected by the UEs, ng-eNB (evolved LTE base station), and gNB. The UE could be a powerful multimedia device (e.g., a smartphone), which is embedded with various positioning sensors. Most UEs could estimate their position based on the downlink signals from numerous sources, such as NG-RAN, GPS, WLAN access points (AP), and Bluetooth. On the other hand, ng-eNB and gNB, as the network elements in the NG-RAN, are responsible for position estimation based on the uplink signals from UEs. The AMF is not directly engaged in location measurement, but it is responsible for the routing between the NG-RAN and LMF. In addition, the AMF also deals with LCS requests and responses, when positioning service is initiated and terminated, respectively. The connection between UEs and NG-RAN follows the LPP protocol, while the communications between NG-RAN and AMF are specified in the NRPPa protocol.

2. General Positioning Procedure in 5G NR

As shown in Figure 2, the 5G NR positioning procedure consists of five steps. The first step is to generate requests, which could be initiated by UEs, the 5G core network, or the AMF. No matter the source of the generated request, the AMF conveys the positioning request to the LMF in Step 2, which manages the following positioning procedure. Then, depending on the positioning method selected by the LMF, the position of the UE is estimated by the NG-RAN node, LMF, or the UE itself. In Step 4, regardless of the source of the positioning result, the LMF collects all the available positioning results and sends the final location results to the AMF as the LCS response. Finally, the AMF conveys the LCS response back to the original source of the LCS request.

NEW POSITIONING REFERENCE SIGNALS IN 5G NR

With the expansion of bandwidth and the evolution of the network elements in 5G, new positioning reference signals are introduced in 3GPP standards to improve the positioning performance, which includes the uplink and downlink signals [11].

1. Uplink-Sound Reference Signal

The uplink signal used in 5G is termed Uplink-Sound Reference Signal (UP-SRS) [11]. The SRS is firstly proposed and used in LTE networks, which is transmitted by the UEs as uplink signals to the eNodeB. The SRS includes the channel state information (CSI) of the uplink wireless channels of all accessible UEs. Thus, the eNodeB can optimize the communication quality with proper resource allocation. Furthermore, the SRS signal is also an effective positioning reference signal because the UE's location is a dominant impact factor on the wireless channel. The proposed 5G positioning methods, such as UL-TODA and UL-AoA, are all based on the SRS signal collected by the eg-eNB or gNB. In 5G NR, the SRS utilizes selected 1, 2, or 4 consecutive symbols, while only one symbol is used for SRS in the LTE. In addition, one antenna port can support more UEs for SRS transmission in 5G. The maximum UE number for simultaneous SRS transmission has been increased from 8 UEs to 12UEs in 5G NR. With the improvement of symbols and UE capacity in the SRS signal, the NG-RAN Node can achieve better wireless communication quality as well as higher positioning performance.

TABLE 3. Supported Versions of General Positioning Methods Used in 5G NR

Positioning Method	UE-based	UE-assisted, LMF-based	NG-RAN assisted
A-GNSS	Yes	Yes	No
Sensor	Yes	Yes	No
WLAN	Yes	Yes	No
Bluetooth	No	Yes	No
TBS	Yes	Yes	No
OTDOA	No	Yes	No
DL-TDOA	Yes	Yes	No
DL-AoD	Yes	Yes	No
Multi-RTT	No	Yes	Yes
E-CID	No	Yes	Yes
NR E-CID	No	Yes	Yes
UL-TDOA	No	No	Yes
UL-AoA	No	No	Yes

2. Downlink-Positioning Reference Signal

The downlink signal used for positioning assistance is Downlink-Positioning Reference Signal (DL-PRS) [11]. Different from UL-SRS, DL-PRS is initially designed for the UE positioning service, which is widely used in RAT-dependent positioning methods. The NG-RAN transmits DL-PRS in various wireless beams, which is generated by antenna arrays at the base station. The beam structure of PRS could benefit beamforming for millimeter wave (mmWave) transmissions in 5G, as well as providing the Received Signal Time Difference (RSTD) for each beam. The UE estimates the gNB position with Angle of Departure (AoD) based on the RSTD and reports the results to the LMF. The bandwidth of PRS is configurable at each gNB, ranging from 100MHz to 400MHz. Furthermore, the repetition gap of the PRS is also configurable in the NG-RAN, so sufficient PRS measurements could be collected for positioning. The flexibility in configuring the bandwidth and signal repetition helps to significantly improve the performance of downlink-signal-based positioning methods, such as DL-AoD and DL-TDOA.

GENERAL POSITIONING METHODS IN 5G NR

To meet the 5G positioning requirements as discussed earlier, various 5G specific positioning methods are considered in 3GPP standards [10]. As discussed earlier, the LCS in 5G NR involves various positioning methods, including RAT-dependent technologies and RAT-independent techniques. The positioning data sources of RAT-dependent methods are the base stations in cellular networks, as in E-CID, OTDOA, Multi-RTT, and AoA methods. In contrast, RAT-independent means localization is measured based on the data from other devices, such as GPS, Terrestrial Beacon System (TBS), Bluetooth, and other sensors. In the 5G NR network, the LMF may leverage any available positioning methods to enable accurate UE positioning. In different scenarios, these positioning methods could be supported in different operating versions, such as UE-based version, LMF-based (UE-assisted) version, and NG-RAN-assisted. The UE-based version means the UE location is estimated by the UE itself, while the LMF-based version and the NG-RAN assisted version estimate the UE location at the LMF and NG-RAN nodes.

The currently supported versions of all general positioning techniques are summarized in Table 3. As the table shows, several RAT-independent positioning methods are introduced in 3GPP standards, which are supported by both UE-based version and LMF-based version. With two available positioning versions, the LMF can decide whether to execute position estimation based on the UE condition. The downlink-signal-based positioning methods, such as DL-TDOA and DL-AoD, are also supported by both UE-based and LMF-based versions.

On the other hand, the positioning methods utilizing the uplink signal, such as Multi-RTT, E-CID, UL-TDOA, and UL-AoA, do not support the UE-based version. However, they can be executed in the LMF-based and NG-RAN version. The optional supported versions help to substantially improve the adaptability of the position service and overall localization accuracy in different scenarios.

CONCLUSION

In this paper, we provided an overview of the 3GPP positioning standards in cellar networks. We reviewed the evolution of positioning methods under various emerging demands for positioning service in cellular networks. We also introduced the current positioning requirements in 3GPP standards, as well as the new techniques to address such requirements, such as the new 5G NR positioning architecture, the new positioning reference signals, and the new positioning methods. ■

This work is supported in part by the NSF (ECCS-1923163).

Chao Yang received his B.S. degree in Electrical Engineering from Yanshan University, He'bei, China in 2015, and his M.S. degree in Electrical and Computer Engineering (ECE) from Auburn University, Auburn, AL in 2017. He has been pursuing a Ph.D. in ECE at Auburn University since Spring 2018. His current research interests include health sensing, indoor localization, Internet of Things and wireless networks. CZY0017@tigermail.auburn.edu

Shiwen Mao received his Ph.D. in Electrical Engineering from Polytechnic University, Brooklyn, NY in 2004. He a professor, the Earle C. Williams Eminent Scholar, and the Director of the Wireless Engineering Research and Education Center at Auburn University, Auburn, AL. His research interests include wireless networks, multimedia communications, and smart grid. He is an IEEE Fellow. smao@ieee.org

Xuyu Wang received his M.S. in Signal and Information Processing in 2012 from Xidian University, Xi'an, China. He received his Ph.D. in ECE from Auburn University, Auburn, AL, USA in Aug. 2018. He is an Assistant Professor in the Department of Computer Science, California State University, Sacramento, CA. His research interests include indoor localization, deep learning, and big data. xuyu.wang@csus.edu

REFERENCES

[1] S.M. Razavi, et al. April 2018. Positioning in cellular networks: Past, present, future. *Proc. IEEE WCNC'18*, Barcelona, Spain, 1-6.
[2] C.R. Saraiva. Jan. 2017. Evolution of positioning techniques in cellular networks, from 2G to 4G. *Hindawi Wireless Communications and Mobile Computing*, vol.2017, Article ID 2315036, 1-17.
[3] X. Wang, S. Mao, and M.X. Gong. Sept. 2017. An overview of 3GPP cellular vehicle-to-everything standards. *ACM GetMobile*, vol.21, no.3, 19-25.
[4] S. Dwivedi, et al. Feb. 2021. Positioning in 5G networks. *arXiv:2102.03361*, Feb. 2021. https://arxiv.org/abs/2102.03361.
[5] 3GPP, Radio Resource Control (RRC) protocol specification. *Technical specification (TS)* 25.331 https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=1180.
[6] 3GPP, Evolved Universal Terrestrial Radio Access (E-UTRA); LTE Positioning Protocol (LPP). *TS 36.355*. https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=2441.
[7] 3GPP, NG-RAN; NR Positioning Protocol A (NRPPa). *TS 38.455*. https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=3256.
[8] 3GPP, Study on scenarios and requirements for next generation access technologies. *TR 38.913*. https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=2996
[9] 3GPP, Study on NR positioning support. *TR 38.855*. https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=3501
[10] 3GPP, NG Radio Access Network (NG-RAN); Stage 2 functional specification of User Equipment (UE) positioning in NG-RAN. *TS 38.305*. https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=3310
[11] 3GPP, NR; Physical channels and modulation. TS 38.211. https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=3213