Prospective Positioning Architecture and Technologies in 5G Networks

Ying Liu, Xiufang Shi, Shibo He, and Zhiguo Shi

Abstract

Accurate and real-time positioning is highly demanded by location-based services in 5G networks, which are currently being standardized and developed to achieve significant performance improvement over existing cellular networks. In 5G networks, many new envisioned technologies, for example, massive Multiple Input Multiple Output (MIMO), millimeter Wave (mmWave) communication, ultra dense network (UDN), and device-to-device (D2D) communication, are introduced to not only enhance communication performance but also offer the possibility to increase positioning accuracy. In this article, we provide an extensive overview of positioning architectures in previous generations of cellular networks to show a road map of how positioning technologies have evolved in past decades. With this insight, we then propose a general positioning architecture for 5G networks, by exploiting the new features of emerging technologies wherein. We also investigate positioning technologies that have great potential in achieving sub-meter accuracy in 5G networks, and discuss some of the new challenges and open issues.

Introduction

Cellular positioning has received great attention over the past decades. It was first introduced to provide a subscriber safety service (i.e., E-911) [1]. With the increasing demand for location information, positioning has become an essential component in cellular networks, enabling location-based services and assisting communication. Although the Global Navigation Satellite System (GNSS) provides a precise location estimation of user equipments (UEs), it has high power consumption and poor positioning performance in indoor environments. Further, GNSS can be applicable only for active positioning with user involvement. This makes cellular positioning a desirable complement to GNSS positioning.

Recently, with the explosive growth of location-based services, cellular positioning needs to meet much higher performance requirements than ever. The U.S. Federal Communication Commission requires that cellular network operators should have the capability of locating UEs with accuracy of 1 meter by 2020. In addition, some emerging applications in 5G networks require higher performance of positioning, for instance, in assisted living, accurate location information is necessary for caretakers or the emergency center to provide real-time assistance. Also, the UE's location information can serve as a proxy for channel information, resulting in efficient power allocation. Further, the base station (BS) can exploit user location information to perform beamforming by steering its transmission, which could substantially improve system capability and spectral efficiency.

It is envisioned that 5G networks should be capable of locating a UE with an accuracy of sub-meter and with high network utility [2], e.g., seamless coverage, low delay and high throughput, which imposes higher requirements for cellular communication systems. Fortunately, some emerging technologies, introduced to meet the communication performance requirements of 5G networks, could be exploited for positioning as well, such as massive MIMO, mmWave communication, UDN and D2D communication. While there have been intermittent studies recently on positioning in 5G networks, a general architecture integrating all emerging technologies and existing positioning architecture in the fourth-generation (4G) is pressingly needed, which is the main focus of this article.

The remainder of this article is organized as follows. In the following section, we provide an overview of positioning architectures and technologies in the second-generation (2G) to 4G networks. Following that, we propose a prospective positioning architecture for 5G networks. Then we investigate the promising positioning technologies in 5G networks, where challenges and open research issues are provided. Finally, conclusions are drawn in the last section.

Overview of Positioning in 2G-4G Networks

Before presenting the general architecture for 5G networks, we first provide an overview of positioning architectures and technologies in 2G-4G networks.

Positioning Architecture

In a typical positioning architecture of the evolved cellular networks, there are three key network elements, target, server and client, as shown in Fig. 1. A target is a UE that needs to be located. A server collects various location-related information and conducts an estimation of the target's location. A client is an entity that sends a positioning request to the network in order to acquire the location information of the target; it could be the target itself or a third-party entity. A complete positioning architecture mainly consists of two parts: core network (CN) and radio access network (RAN), which will be introduced in detail in the following.

In 2G networks, RAN, which consists of base transceiver stations (BTSs) and base station controllers (BSCs), is mainly in charge of radio resource management. The serving mobile location center (SMLC) is a server for collecting various measure-

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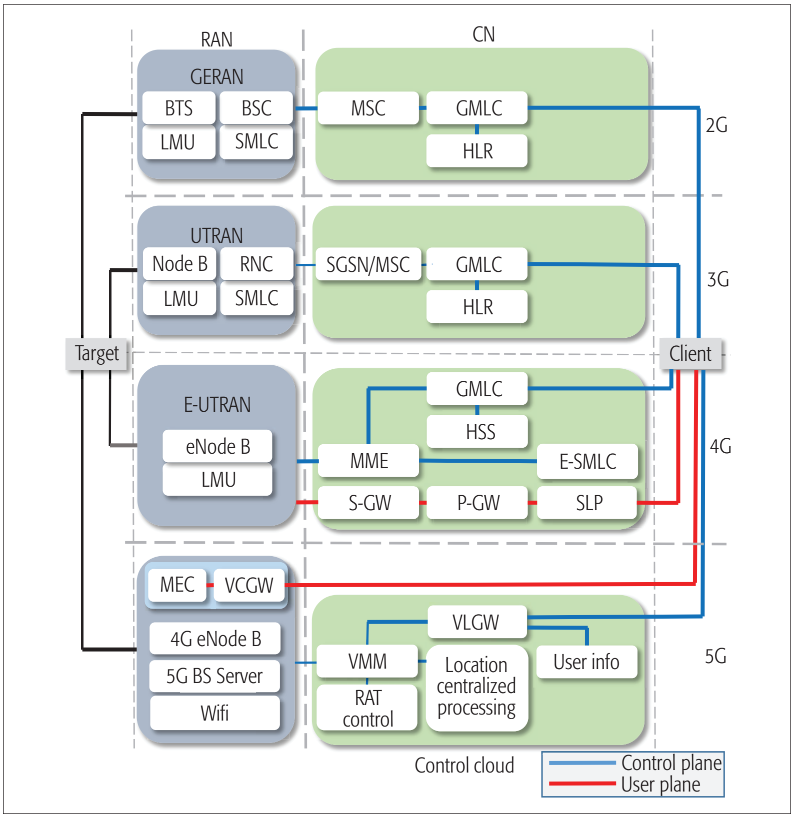

FIGURE 1. Positioning architectures of evolved cellular networks.

ments and calculating the target's location. It could be either a stand-alone location server, or an integral part of the BSC. At the beginning of a positioning process, the client sends a positioning request to the gateway mobile location center (GMLC) in the CN, which collects basic information about the target from the home location register (HLR). Then the positioning request is sent by the GLMC to its corresponding mobile switching center (MSC), which forwards it to the BSC and SMLC. Once the SMLC receives the request, it measures location-related information or collects all measurements from the BTS, and calculates the location of the target. Eventually, the positioning result will be returned to the client.

The positioning architecture of third-generation (3G) networks is similar to that of 2G networks [3]. The radio network controller (RNC) plays a similar role as BSC. The main difference is that the positioning request is sent by the GMLC to the MSC and serving general packet radio service support node (SGSN). The location measurement unit (LMU), a specific hardware component that was first introduced in Wideband Code Division Multiple Access (WCDMA), will conduct a measurement upon receiving a positioning request from the RNC. An LMU could be either a standalone unit or be integrated with the BS, i.e., Node B, and has now been used in hybrid cellular networks.

In 4G networks, the positioning architecture is significantly different from those of 2G and 3G networks [4]. The RNC is removed and some of its functionality is integrated into the BS, called eNode B. In 2G and 3G networks, target positioning is only performed in the control plane, while 4G networks support positioning in both the control plane and user plane. As shown in Fig. 1, the control-plane positioning process chain is shown in blue, while the user plane positioning process chain is in red. Long Term Evolution (LTE) supports the LTE Positioning Protocol (LPP), which is a communication protocol between the server and the target and is used in both the control plane and user plane to localize the target. In the control plane, location-related information is exchanged over control channels using LPP and a communication protocol between the server and eNode B-LPP Annex (LPPA). The client starts the positioning process by sending a positioning request to the GMLC. Then, the mobility management entity (MME) receives the request from the GMLC and transmits it to the evolved serving mobile location center (E-SMLC), which chooses proper positioning methods and calculates the location of the target with the returned location-related information and measurements from the UE and eNode B. In the user plane, location-related information is exchanged over data channels using a protocol called Secure User Plan Location (SUPL), in which the UE and eNode B send relevant measurements to the SUPL location platform (SLP) via the S-GW and P-GW. After collecting location-related information, the SLP calculates the location of the target and sends the estimated location to the client.

Positioning Technologies

To estimate the target's location, the server needs to select specific positioning methods and conduct corresponding measurements according to the environment and the target device capabilities. The available positioning methods can be divided into four basic categories[5]:

- Cell identity (CID)-based methods, in which the location of the serving BS is incorporated to estimate the UE's location.
- Range-based methods, in which range-related measurements, e.g., time of arrival (TOA), time difference of arrival (TDOA) and received signal strength (RSS), are utilized to estimate the UE's location.
- Angle-based methods, in which the angle of arrival of radio signals is utilized to estimate the UE's location by triangulation.
- Fingerprinting-based methods, in which the location is estimated by comparing online measurements with a set of training samples at known positions.

We summarize positioning technologies and positioning performance in 2G-4G networks in Table 1.

In 2G networks, the standard CID is utilized [1]. Its positioning performance is poor since the cell size (coverage range) of a BS is very large (up to 35 km). Another method, the Enhanced Observed Time Difference (E-OTD) based method, is also implemented, and it is essentially a TDOA positioning method that can provide a positioning accuracy of 50~300m, higher than that of CID but requiring time synchronization. Timing advance (TA) is introduced to realize time synchronization and to assist the CID-based method to improve its positioning accuracy to about 550 m.

In 3G networks, with smaller cells and combined with round-trip time (RTT), the accuracy of CID-based positioning is about 200 m, higher than that of 2G networks, and the response

Network	Synchronization	Method	Limitations	Accuracy	Response time
2G	Timing advance	CID+TA	Cell sizes	About 550 m	Very low
		E-OTD	Multipath	50~300 m	Medium
3G	Synchronization symbols	CID+RTT	Cell sizes	About 200 m	Low
		OTDOA	Multipath	50~200 m	Medium
		A-GPS	Weak indoor reception	10~50 m	High
4G	PRS	ECID	Cell sizes and multipath	150 m or coarser	Low
		OTDOA or UTDOA	Multipath	50~200 m	Medium
		A-GNSS	Weak indoor reception	10 m or more precise	High

TABLE 1. Positioning technologies and corresponding performances in evolved cellular networks.

time is short. As for TDOA-based methods, Observed Time Difference of Arrival (OTDOA), which is based on downlink signals, is also specified. Two technologies, idle period for the downlink (IPDL) and the fix unit-LMU, can improve the positioning accuracy of OTDOA. LMU could get location-related measurements with high accuracy, and IPDL's occurrence is aware by UEs to arrange the time difference measurements accordingly. The positioning accuracy of OTDOA is about 50$\sim$200 m, higher than that of CID while it can be affected by multipath. Furthermore, Global Position System (GPS) modules are widely installed in UEs. Assisted GPS (A-GPS) is adopted to accelerate the acquisition of satellite signals for GPS by establishing a GPS reference network connected with the cellular infrastructure. This method can provide high positioning accuracy (i.e., 10$\sim$50m) in high-visibility environment, however, its response time is high.

In 4G networks, positioning methods based on those of 3G networks have been improved [3]. UEs are equipped with multiple antennas, which enables the utilization of AOA measurements in positioning. To assist CID-based positioning, AOA and other measurements are adopted in enhanced CID (ECID), whose accuracy is about 150 m or coarser, much better than that of the standard CID. Nevertheless, limited by the number of antennas, AOA measurements suffer from multipath, which will degrade the performance of ECID. TDOA-based methods are also available in 4G networks. Uplink-TDOA (UTDOA) based on uplink signals is introduced. Moreover, the positioning reference signal (PRS) is newly specified for measuring TDOA with higher accuracy. To locate UEs precisely and rapidly, assisted GNSS (A-GNSS), adopted to provide an accuracy of 10 m or better, is an evolution of A-GPS and involves some other GNSSs like Galileo and Beidou navigation systems. Today, these methods are widely used in hybrid cellular networks.

Positioning Architecture in 5G Networks

It has been claimed that 5G networks will not be a simply incremental evolution of 4G networks. In order to meet the higher positioning performance requirement, a general positioning architecture integrating emerging communication technologies and based on previous architectures is needed. In this section, we propose a prospective positioning architecture for 5G networks based on emerging technologies in 5G networks. As shown in Fig. 2, the proposed architecture mainly consists of two parts: a RAN, which includes a multi-radio access technology (RAT) network and edge cloud, and control cloud, which is a new element different from the previous generations of networks. We will introduce these parts in detail.

In 5G networks, seamless coverage and a flawless user experience are highly demanded. For this, RATs, such as LTE, 5G, WLAN and other licensed assisted access, are envisioned to be utilized for tight integration, with configurable capability according to the environment and mobility requirements of users.

Multi-RAT Network

In 5G networks, seamless coverage and a flawless user experience are highly demanded. For this, RATs, such as LTE, 5G, WLAN and other licensed assisted access [6], are envisioned to be utilized for tight integration, with configurable capability according to the environment and mobility requirements of users.

Clearly, the serving RAT partly determines the positioning method to be selected. A UE could hand over to a particular RAT in specific environments, for example, utilizing WLAN in indoor environments may provide better positioning performance. In a multi-RAT positioning system, the most desirable positioning method should be selected considering the capabilities of the UE and positioning quality of service (QoS).

A multi-RAT network integrates some emerging technologies in 5G networks, resulting in an improvement of positioning accuracy, for example, densely distributed radio access nodes like micro/pico/femto cellular BSs and WiFi access nodes are closer to the UEs, which will intuitively improve the positioning accuracy of CID-based methods. Moreover, BSs will be equipped with hundreds of antennas, which is beneficial for precisely obtaining AOA measurements.

Edge Cloud

As illustrated in Fig. 2, the edge cloud is located at the edge of a RAN to support user plane positioning. It mainly consists of a virtual converged gateway (VCGW) and mobile edge computing (MEC) server.

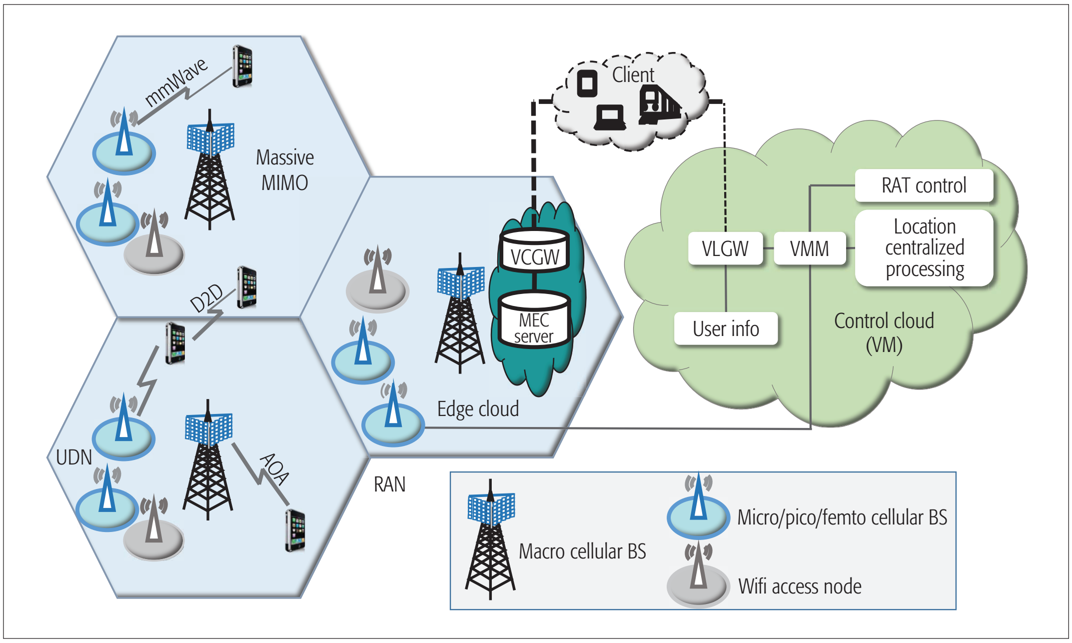

FIGURE 2. 5G intuitive positioning architecture.

MEC is an emerging paradigm to cope with the increasing computation demands from UEs. Compared with cloud computing, MEC overcomes the limitation of large latencies by processing large volumes of data and workloads locally at the edge of the network, resulting in real-time positioning.

The VCGW is responsible for user plane functions, for example, QoS management and accommodating various access networks. Taking into account the centralized processing feature of 5G networks [7], the VCGW integrates some functions of traditional gateways (e.g., P-GW and S-GW in LTE), reducing the complexity and avoiding function redundancy.

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Control Cloud

Control plane functions are integrated in the control cloud. Different from positioning architecture of 2G-4G networks, positioning-related entities (e.g., MME, HSS and E-SMLC in LTE) are removed from the CN and the corresponding functions are implemented on virtual machines (VMs).

As shown in Figs. 1 and 2, the positioning procedure in the control plane is summarized as follows. The client first sends a positioning request to the virtual location gateway (VLGW), which obtains basic information about the target. Location-related information and the location permission of the UE is obtained by the virtual manages mobility (VMM) module. Then, the positioning center chooses an appropriate RAT, collects measurements from multiple BSs and UEs, and estimates the location of the target. Ultimately, the result will be returned to the client.

Differences between 5G and 2G-4G Networks

Compared with the positioning architectures of 2G-4G networks, the proposed architecture for 5G networks has the following features:

- Multiple RATs are utilized and could be selected adaptively according to environments (e.g., space size and various signal strength around), device capabilities and positioning QoS.
- The edge cloud and control cloud are mainly based on software defined network (SDN) and network function virtualization (NFV)[8], which could bring flexibility, network virtualization and deep programmability. Positioning-related entities are removed by integrating their functions into VMs, which can lower the complexity and processing time.
- Control plane functions and user plane functions are separated entirely. Positioning can be implemented in either the user plane or control plane, determined by the requirements of positioning QoS. By separating the user plane and control plane, real-time positioning could be performed in the user plane at the edge of the RAN to lower communication delay. Positioning in the two planes could complement each other well to enhance positioning performance.

Positioning Technologies in 5G

Considering the evolution of cellular networks, various technologies have been introduced in evolved versions of communication standards, such as TA in 2G networks, IPDL in 3G networks, and PRS in 4G networks, which benefit positioning to a large extent. Given these considerations, several promising technologies envisaged in 5G networks in order to meet the challenges related to communication are also potentially beneficial for positioning. In this section, we investigate four of the most relevant technologies for UE positioning, and discuss the recent achievements and the open research issues to be addressed.

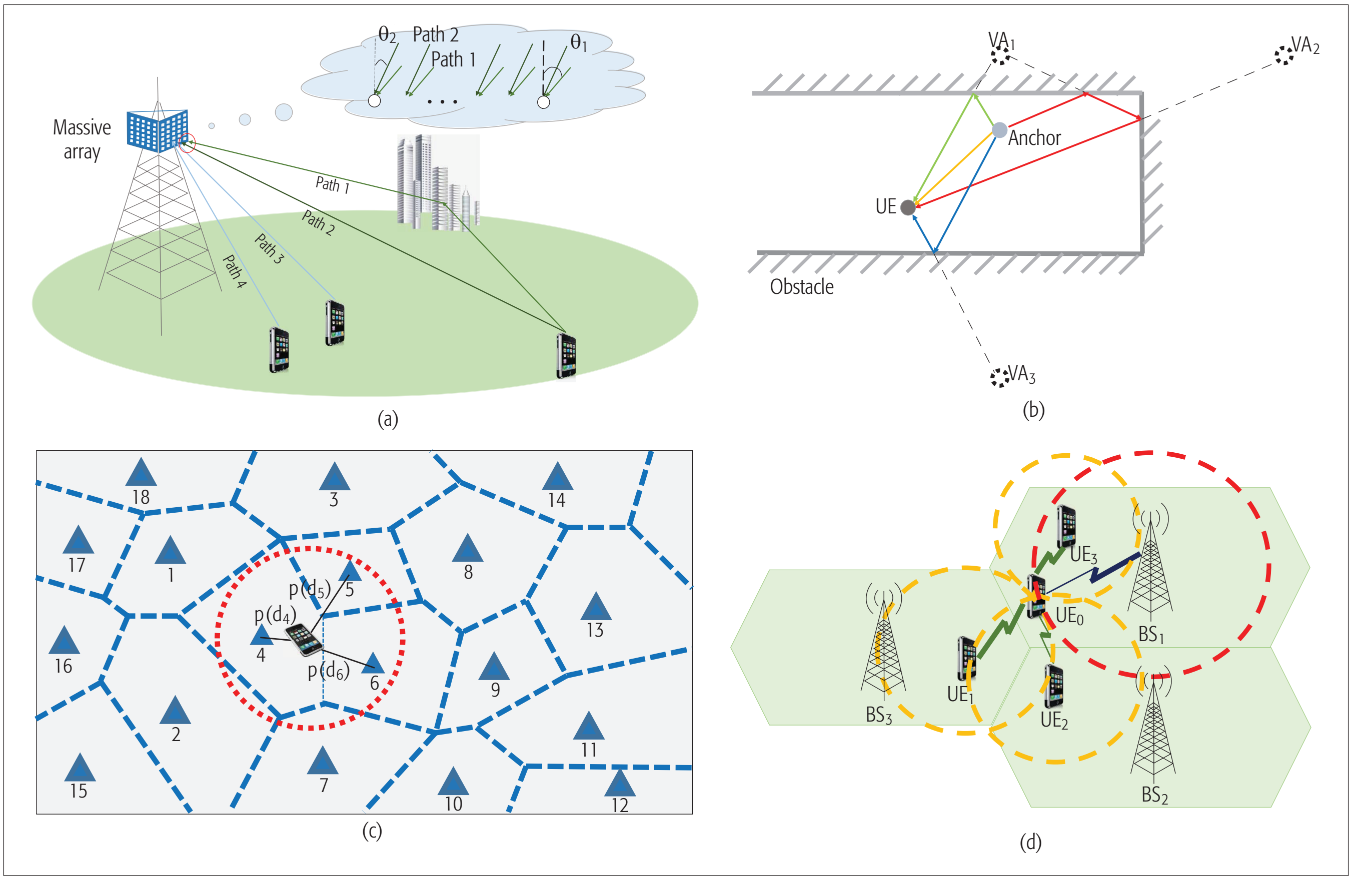

FIGURE 3. Positioning technologies based on four envisioned technologies in 5G networks. a) Massive arrays could conduct LOS/NLOS identification and the UE's location is estimated based on LOS AOAs. Furthermore, the accuracy of AOA measurements could be improved with a large array aperture. b) In an indoor area, mmWave signals are transmitted by a physical anchor and received by the UE via multiple paths. The orange line stands for LOS transmission; the blue line and green line denote the paths with first-order refection; the red line shows the path with second-order reflection. Based on the locations of the physical anchor and virtual anchors (VA_1, VA_2, VA_3), the UE can be localized. c) In a UDN, the distribution of small cells is modelled by PPP, based on which, the PDFs of the distances between the UE and its three nearest BSs are $p(d_4)$, $p(d_5)$, and $p(d_6)$, respectively. Combining $p(d_4)$, $p(d_5)$, and $p(d_6)$, the UE's location can be estimated via statistical processing approaches. d) Through D2D communication, UE_1, UE_2 and UE_3 play as pseudo BSs and provide additional location-related information for the positioning of the target UE_0.

Massive MIMO

In 5G networks, with massive MIMO, the BS will be equipped with hundreds or even thousands of antennas, which can provide a large array aperture. By analyzing the uplink channels using pilot signals sent by the UEs, the BS can estimate the AOAs with high accuracy and low inter-user interference effect. Therefore, massive MIMO will boost the utilization of angle-based positioning approaches in 5G networks, which are not widely used in 2G-4G networks.

In practice, as shown in Fig. 3a, positioning requests often occur in dense multipath environments, where, for a single UE, multiple AOA measurements from multiple paths will be obtained at each BS and only the line-of-sight (LOS) measurements can precisely reflect the angular relationship between the UE and the BS. Appropriate processing of measurements is essential for accurate positioning. One typical positioning approach is a two-step approach, which first conducts LOS/none-line-of-sight (NLOS) identification and then selects the LOS measurements for positioning. However, an LOS path may not even exist in the multipath environments where all signals are NLOS propagated.

With massive MIMO, one BS can serve multiple UEs and will receive multiple signals. These signals are usually coming from coherently distributed sources or incoherently distributed sources, and various AOA estimation algorithms have been proposed, e.g., the multiple signal classification (MUSIC) algorithm, estimating signal parameters via rotational invariance technique (ESPRIT) algorithm [9, 10], and so on. Note that location estimation for each UE is based on the measurements associated with it. Therefore, source association is a key problem for multiple source positioning in massive MIMO systems, which, however, has not been well addressed.

With regards to positioning in massive MIMO systems, there are still several open research issues, for example, NLOS measurement modelling in multipath environments where there is no LOS measurements, the influence of mutual coupling in the massive antenna array on location accuracy, and source association for multiple UE positioning.

mmWave Communication

mmWave communication, a promising technology for achieving high data rate and low latency communication in 5G networks, offers great potential in improving positioning performance

UDN is a promising technology to meet the demand of area coverage and capacity in 5G networks. In a UDN, there are a large number of small cells that can be played as fully-functioning BSs (picocells and femtocells) or macro-extension access points (relays and remote radio heads)

in complex environments, especially dense multipath indoor or urban areas. In a dense multipath environment, with a very large signal bandwidth, mmWave communication enables the high separation of multipath components. Moreover, to mitigate high signal attenuation due to the high carrier frequency, mmWave usually adopts directional beamforming, with which AOAs can be accurately extracted and the probability of interference will also be reduced. Benefitting from the above aspects, mmWave communication will turn multipath from a foe into a friend with regards to positioning [11].

As shown in Fig. 3b, in an indoor area, the UE can receive mmWave signals from multiple paths transmitted by a physical anchor (access point or BS). The received signals might have been reflected by a wall or other obstacles on their paths from the anchor and to the UE. Based on the AOA and time delay measurements, the position of the virtual anchor (VA) corresponding to each path can be estimated since VAs and the physical anchor are mirrored with respect to the reflectors. Combing the positions of the physical anchor and VAs with the corresponding location-related measurements (AOA, TOA, etc.), the UE's location can be calculated by many well-studied algorithms, for example, MLE, LS, etc. In addition to the positioning of the UE, the environmental map can be constructed in the mean time, namely, simultaneous positioning and mapping (SLAM). Such an approach does not rely on prior knowledge of the surrounding environment. Moreover, only one physical anchor is sufficient for achieving decimeter or even centimeter level accuracy.

On account of positioning in multipath environments utilizing mmWave communication, the existing studies mainly focused on the utilization of the signals that have been reflected on their paths only once, i.e., first-order reflection, for analysis simplicity, whereas in dense multipath environments, multiple reflections, i.e., higher-order reflections, occur. The investigation about paths with higher-order reflections can help improve positioning and mapping, which is of great significance and yet challenging.

UDN

UDN is a promising technology to meet the demand of area coverage and capacity in 5G networks. In a UDN, there are a large number of small cells that can be played as fully-functioning BSs (picocells and femtocells) or macro-extension access points (relays and remote radio heads) [12]. In addition to high coverage and capacity, positioning performance of UEs can also be improved thanks to the high density of small cells.

Such an improvement in positioning performance can be found in many well-developed positioning methods:

- In CID-based methods, the positioning error will be reduced because of much smaller cell sizes.
- In range-based methods, the high density of BSs will increase the probability of LOS propagation, which will increase the accuracy of location-related measurements, e.g., AOA, TOA, etc.

Furthermore, UDN will enable new promising positioning methods. In a UDN, the spatial distribution of small cells is usually modelled by stochastic geometry, for example, Poisson point process (PPP). As shown in Fig. 3c, given a density of BSs, we can easily calculate the probability density function (PDF) of the distance between the UE and its k-th nearest BS, and thereby estimate the distances between the UE and its neighboring BSs. The location of the UE can be estimated by trilateration using the estimated UE-BS distances, or by statistical processing approaches using the PDFs of UE-BS distances[13]. Such an approach does not need to conduct ranging between the UE and BSs. Its accuracy is expected to be higher than that of the CID-based approach.

Though UDN is beneficial for UE positioning in 5G networks, there are still a few open research issues. For example, clock synchronization between multiple small cells is essential for TOA based positioning approaches, which has not been fully investigated in UDN. Idle mode capabilities of UDN, which is important for interference mitigation among neighboring BSs, will also influence the positioning performance. How to coordinate BSs is important for accurate positioning as well.

D2D Communication

In D2D communication, two nearby devices can communicate and exchange data without involvement of BSs [14, 15]. Such a technique can also assist in locating UEs in 5G networks and boost new positioning mechanisms.

For a target UE, through D2D communication, it can obtain the relative distances or azimuth angles to other UEs, called assisted UEs, which could communicate with the target UE. If the target UE has sufficient access to BSs for positioning, D2D communication can help improve the positioning accuracy with assisted UEs acting as additional anchors. In many complex environments, e.g., dense urban or indoor environments, a target UE is possibly in an NLOS environment and even may not have direct access to BSs. In this scenario an assisted UE can play as a pseudo BS or help establish a link between the target UE and the BS. If an assisted UE plays as a pseudo BS, its location is important for the positioning of the target UE. Since the location of assisted UEs might be inaccurate or even unknown, how such inaccuracy affects positioning performance and how to eliminate such influence are two key problems to be solved. Moreover, multi-hop based approaches can also be applied to D2D-aided positioning in cases where one-hop information is insufficient for positioning. There are some key problems to be solved in multi-hop based approaches, e.g., how to conduct location estimation using multi-hop information, how to balance the hop number and the positioning accuracy, etc.

In addition to the positioning accuracy of the target UE, privacy concerns on the transmitting and receiving sides of D2D communication cannot be neglected in D2D-aided positioning. How to protect the location privacy of the UEs without impacting positioning accuracy is a challenging issue that needs further investigations.

Future Work

Our future work will focus on two aspects. First, as can be seen from the positioning architecture of 5G networks, multiple emerging technologies will be integrated into the RAN part to provide complementary advantages for positioning in 5G. We will explore algorithmic designs combining prospective technologies to realize high-performance positioning. Second, we will study positioning related issues introduced by the integration of multiple emerging technologies in the positioning architecture, such as adaptive RAT control in dynamic environments, mobility management for mobile devices and radio resource allocation, etc..

Conclusion

In this article, we provided an extensive overview of the architectures and technologies in 2G-4G networks. We proposed a prospective positioning architecture for 5G networks based on multi-RAT, network virtualization as well as MEC, to meet the needs in terms of coverage, time delay and positioning accuracy in 5G networks. We also introduced feasible positioning technologies based on four emerging communication technologies, that is, massive MIMO, mmWave communication, UDN and D2D communication, and discussed related open research issues.

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References

[1] C. Drane, M. Macnaughtan, and C. Scott, "Positioning GSM Telephones," *IEEE Commun. Mag.*, vol. 36, no. 4, Apr. 1998, pp. 46–54.
[2] J. Chen *et al.*, "Utility-Based Asynchronous Flow Control Algorithm for Wireless Sensor Networks," *IEEE JSAC*, vol. 28, no. 7, Sept. 2010, pp. 1116–26.
[3] A. M. Bravo, J. I. Moreno, and I. Soto, "Advanced Positioning and Location Based Services in 4G Mobile-IP Radio Access Networks," *Proc. PIMRC*, Jan. 2004, Barcelona, Spain, pp. 1085–89.
[4] "Positioning with LTE," Ericsson White Paper, 2011.
[5] G. Sun *et al.*, "Signal Processing Techniques in Network-Aided Positioning: A Survey of State-of-the-Art Positioning Designs," *IEEE Signal Proc. Mag.*, vol. 22, no. 4, Jul. 2005, pp. 12–23.
[6] P. Marsch *et al.*, "5G Radio Access Network Architecture: Design Guidelines and Key Considerations," *IEEE Commun. Mag.*, vol. 54, no. 11, Nov. 2016, pp. 24–32.
[7] O. Chabbouh *et al.*, "A Novel Cloud RAN Architecture for 5G HetNets and QoS Evaluation," *Proc. ISNCC*, May 2016, Yasmine Hammamet, Tunisia, pp. 1–6.
[8] J. Zhang, W. Xie, and F. Yang, "An Architecture for 5G Mobile Network Based on SDN and NFV," *Proc. ICWMMN*, Nov. 2015, Beijing, China, pp. 87-92.
[9] L. Wan *et al.*, "DOA Estimation for Coherently Distributed Sources Considering Circular and Noncircular Signals in Massive MIMO Systems," *IEEE Syst. J.*, vol. 11, no. 4, Mar. 2017, pp. 41–49.

In addition to the positioning accuracy of the target UE, privacy concerns on the transmitting and receiving sides of D2D communication cannot be neglected in D2D-aided positioning. How to protect the location privacy of the UEs without impacting positioning accuracy is a challenging issue that needs further investigations.

[10] A. Hu *et al.*, "An ESPRIT-Based Approach for 2-D Localization of Incoherently Distributed Sources in Massive MIMO Systems," *IEEE J-STSP*, vol. 8, no. 5, Mar. 2014, pp. 996–1011.
[11] P. Meissner *et al.*, "High-Accuracy Localization for Assisted Living: 5G Systems will Turn Multipath Channels from Foe to Friend," *IEEE Signal Proc. Mag.*, vol. 33, no. 2, Mar. 2016, pp. 59–70.
[12] M. Kamel, W. Hamouda, and A. Youssef, "Ultra-Dense Networks: A Survey," *IEEE Commun. Surv. Tut.*, vol. 18, no. 4, May 2016, pp. 2522–45.
[13] A. Gopakumar and L. Jacob, "Power-Aware Range-Free Wireless Sensor Network Localization Using Neighbor Distance Distribution," *Wireless Commun. Mob. Com.*, vol. 13, no. 5, Apr. 2013, pp. 460–82.
[14] J. Liu *et al.*, "Device-to-Device Communication in LTE-Advanced Networks: A Survey," *IEEE Commun. Surv. Tut.*, vol. 17, no. 4, Dec. 2015, pp. 1923–40.
[15] J. Liu *et al.*, "Device-to-Device Communications Achieve Efficient Load Balancing in LTE-Advanced Networks," *IEEE Wireless Commun.*, vol. 21, no. 2, Apr. 2014, pp. 57–65

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