**Frontiers in Computing and Intelligent Systems**
ISSN: 2832-6024 | Vol. 5, No. 1, 2023

# Research on Intelligent Indoor Positioning Technology based on 5G

**Xuelin Han and Liangfu Peng ***

Southwest Minzu University, Chengdu 610041, China
*** Corresponding author:** Liangfu Peng

**Abstract:** 5G, as the first mobile communication system that takes positioning service as one of the design goals, introduces a variety of new technologies to improve the communication performance of the system and the accuracy and applicability of wireless positioning. However, there are still some problems in 5G indoor positioning, such as low positioning accuracy and poor switching between indoor and outdoor positioning. In order to solve these problems, further research and improvement of positioning technology is needed. In summary, 5G, as the first mobile communication system that takes positioning service as one of its design goals, introduces a variety of new technologies to improve the accuracy and applicability of positioning. However, there are still some problems to be solved, such as improving indoor positioning accuracy and achieving continuous and seamless coverage for indoor and outdoor positioning. The future development trend is positioning integration and convergence, and the introduction of collaborative positioning techniques to further improve the performance of positioning. In this paper, by analyzing the current status of 5G indoor positioning, it leads to the fact that how to improve the indoor positioning accuracy and achieve continuous and seamless coverage of indoor and outdoor positioning are urgent problems in the field of positioning, for which, firstly, we analyze the positioning techniques under the ultra-dense networking for 5G, the AOA, TDOA positioning techniques, and uplink and downlink positioning techniques. Finally, it is pointed out that positioning integration and convergence is the trend of future 5G positioning development, and then the necessity and feasibility of introducing collaborative positioning technology is pointed out.

**Keywords:** 5G Positioning Technology; High Precision Positioning; Channel State Information (CSI); Fifith-Generation (5G) New Radio (NR); Indoor Positioning.

## 1. Introduction

Due to the rapid progress of communication technology, users are getting basic video and voice services while the need for other data services continues to intensify. In daily life, most of the data services need the support of positioning technology, which makes the research on positioning more and more attention. Whether in underground parking lots, mines and other closed places, or factories, homes and other common indoor places, or playgrounds, roads and other broad outdoor scenes, access to positioning information for personnel safety, equipment scheduling and management, travel navigation and other business needs to provide more important information support. At the same time, the development of the fifth-generation mobile communication (5G) system can ensure higher capacity, lower energy consumption and lower delay, which greatly solves the requirements for data transmission in the era of technology. In the face of diversified service scenarios, the ensuing 5G technology has also begun to widely integrate with positioning technology. For this reason, in the 5G era, mobile communication technology is no longer limited to communication functions, but also needs to ensure that the positioning information of communication devices is obtained in order to provide services more efficiently. According to 3GPPRel-18 [1], the goal of 5G New Radio (NR) localization is to achieve a 95% confidence level, with an absolute indoor horizontal error of less than 10 m, and an absolute indoor vertical error of less than 3m.

The current high-precision positioning system based on the Global Positioning System (GPS) has reached an accuracy of 10 meters or even within 10 meters, which can ensure feasible outdoor positioning services as well as positioning needs. However, the obstruction of building walls and the complexity of indoor scenes make it difficult for satellite system signals to achieve accurate and reliable positioning results in indoor environments. Although the outdoor positioning accuracy has basically met the users' needs, realizing indoor high-precision positioning still has more serious challenges. The global market for indoor location-based services is estimated to reach USD 57.24 billion by 2027, growing at a CAGR of 37.92% during the forecast period [2]. In addition, people spend about 87-90% of their time indoors, which is a strong indication of the reliable outlook as well as the growth potential of indoor positioning. Therefore, in order to provide reliable indoor services, more in-depth discussions are needed to compensate for the shortcomings of indoor positioning and to improve the existing indoor positioning techniques, hoping to improve the positioning accuracy of indoor positioning while reducing the cost of data collection as much as possible.

Among them, massive multiple-input multiple-output (MIMO) technology can utilize multiple antennas for data transmission and reception, improving signal reliability and transmission rate [15]. Ultra-dense networks, on the other hand, provide more signal coverage and capacity by increasing the density of base stations, further improving positioning accuracy and applicability. Millimeter-wave transmission, on the other hand, utilizes high-frequency bands for signal transmission, which can provide higher bandwidth and transmission rates, thereby improving positioning accuracy and response time [16]. The introduction of device-to-device communication enables direct communication between devices, which not only improves positioning

accuracy, but also supports some new application scenarios, such as indoor navigation and location sharing.

The 5G fingerprint indoor positioning process is mainly divided into five links: scene model construction, wireless information acquisition, fingerprint library construction, fingerprint information matching, and location tag output.

This paper firstly introduces one of the factors affecting the effect of indoor positioning accuracy, scene model building, and how to optimize the currently existing channel model is still one of the main issues to be explored; secondly, the wireless information acquisition method is outlined; then, based on the classification of the positioning application scene requirements, the indoor positioning scheme based on small base station communication network is proposed, and the advantages of the scheme are specifically elaborated, and the results show that the 5G fingerprint indoor positioning process can meet the needs of the consumer sector and more importantly, the indoor positioning process can meet the needs of the consumer sector. The results show that the indoor positioning scheme based on small base station can satisfy the positioning needs of the consumer field and more extensive vertical industries, which is of great significance and application prospect; finally, the commonly used positioning technologies are introduced and compared, and then the typical application scenarios of different positioning technologies and the feasibility of the positioning process applied in the classical indoor environment are discussed.

# 2. Scene Modeling

Fifth generation mobile communication systems are considered to be the ideal technological solution for solving the generalized indoor localization problem due to their high bandwidth, dense base stations, and large antenna sizes. Indoor scenarios are characterized by a deterministic propagation environment. Statistical channel models have a non-negligible bias in evaluating the positioning performance in specific indoor scenarios, so deterministic channel modeling requires appropriately detailed information about the propagation environment [10].

Common 5G channel modeling methods fall into two main categories, deterministic modeling and statistical modeling [3]. Deterministic modeling focuses on simulating the propagation of a signal in a particular scenario, using techniques such as ray tracing to obtain the impulse response of the channel. The advantage of this method is that the channel model conforms to the deterministic scenario with high accuracy, while the disadvantages of complex modeling, high cost and poor scenario adaptation are difficult to overcome. The second category is statistical modeling methods, which are based on a large amount of channel measurement data. More specifically, the measurement data are analyzed and extracted to obtain the statistical characteristics of the channel parameters in the corresponding scenarios, and then the modeled channel parameters and distribution functions are used to generate random channel parameters. The advantages of this method lie in the adaptability of the channel model to the scenario and the low complexity and cost of modeling. However, it is limited by the fact that the channel parameters are stochastic and have errors from the actual propagation. Overall, the deterministic modeling approach is superior in terms of accuracy, but has higher complexity and cost, and is less adaptable, while the statistical modeling approach is more adaptable, with lower complexity and cost, but with some limitations in accuracy. Therefore, most of the existing 5G channel models are statistical channel models, as 5G channel models are heavily reliant on measurements.

# 3. Wireless Information Acquisition

In indoor environments, path loss is affected by a variety of factors, including the material and structure of the building, the location and number of obstacles, and the movement speed of the terminals. Therefore, the effects of these factors need to be considered when modeling the indoor wireless channel. The wireless channel is the physical propagation environment between the base station and the terminal under wireless communication conditions. In indoor wireless localization, the characteristics of the channel directly determine the accuracy of the parameters used for localization, which further affects the positioning accuracy. Before modeling the wireless channel, a detailed and rational delineation of the operating environment of the communication system is required [14]. Specific scenarios will simultaneously yield more accurate localization parameters and facilitate the evaluation of localization performance. In an indoor environment, the wireless channel is extremely random. Dense 5G base stations, coupled with obstacles and random movement of terminals, greatly increase the difficulty of channel modeling.

Another factor that affects the indoor wireless channel is the multipath effect. As the signal undergoes multiple paths during propagation, there are multiple versions of the signal arriving at the receiver, leading to signal fading and interference. The multipath effect is especially significant in indoor environments because signals are reflected, refracted, and scattered between buildings, creating multiple paths.

Direct radiation is also known as path loss, which means that when a transmitter emits a wireless signal, the energy of the signal is diffused as it travels. Fries' law can be used to describe how it varies. It is generally accepted that the path loss is the same for the same propagation distance. Unlike the traditional path loss model, the path loss model for 5G channels takes the form of Equation (1), where $f_c$ is the carrier frequency, $d_{3D}$ is the three-dimensional distance, and $A$, $B$, and C are the path loss coefficients associated with the scene.

$$PL = A + Blog_{10}(f_c) + Clog_{10}(d_{3D}) \quad (1)$$

In addition to path loss and multipath effects, the channel is also affected by other interferences, such as noise and multi-user interference. These interferences further degrade the quality and reliability of the signal. For indoor wireless localization, understanding the characteristics of the channel is crucial for determining the accuracy of the localization parameters. Therefore, detailed and rational channel modeling is required to accurately characterize the indoor wireless channel. This can be achieved through measured data, simulation and statistical analysis. By modeling the channel, the performance of the positioning system can be better evaluated and the positioning algorithms and parameter configurations can be optimized to improve the positioning accuracy.

Indoor environments are diverse and have different geometries and wireless signal characteristics. Before modeling the 5G wireless channel, a precise and detailed classification of the scene is required, which helps to provide more accurate indoor positioning services based on the positioning needs assessment. Research on the specific

classification of indoor scenes has not attracted much attention in recent years. The following principles should be followed when making classification decisions for specific indoor scenes:

·From the basic characteristics of wireless signal propagation, mainly based on the spatial structure and multipath structure of various indoor scenes; -There is exclusivity between different indoor scenes.

·Exclusivity between different indoor scenes, effectively avoiding the duplication and confusion of scene channel model; -Based on the actual needs of different indoor scenes, such as the requirements of positioning service accuracy and the number of service devices.

Based on the actual needs of different scenes in terms of positioning service accuracy requirements, number of service devices, etc.; -There is no indoor composite scene.

No indoor composite scene.

# 4. Classification based on Positioning Scenarios

Indoor positioning and navigation technology is becoming increasingly mature, popular, has penetrated into many fields and industries, the application of positioning technology is often only concerned about the application itself, but failed to dig from the actual application conditions for the hidden requirements of positioning technology. These requirements often belong to the rigid requirements, but they are most easily ignored by people. In this section, we focus on analyzing the hidden requirements for positioning technology in various typical scenarios from the perspective of application scenario classification, and give the corresponding applicable positioning technologies. In addition, under the development trend of network integration in the future, high-precision positioning will no longer be limited to a single technology or scheme, and the scenario-based positioning classification proposed in this section can better portray its essential characteristics.

## 4.1. WAI Class

WAI, "Where am I", the main feature of such application scenarios is that the subject initiating the positioning claim and the target subject to be measured are the same, and the implicit requirement is that the user is highly cooperative or active positioning, and has high computational power. In the field of civil indoor positioning and navigation, most of the active positioning application scenarios belong to this category, such as personal positioning services in large shopping malls or airports, parking space navigation, and indoor exhibition hall route guidance. Users take the initiative to make positioning requests, and the source data required for positioning, including but not limited to clock information, frequency band information, channel status, arrival time and so on. Methods that can be used in such positioning scenarios include ToF/ToA, TDoA, RSSI, fingerprint positioning, satellite positioning, and pedestrian navigation position projection.

## 4.2. WAU Class

WAU, "Where are you", this kind of application scenario is mainly characterized by the fact that the subject initiating the positioning claim is not the same as the subject of the target to be tested, but there is a connection between the two, and the implied implicit requirements are a high degree of cooperation of the user to be positioned, the support of a high computational power, and a network with both communication and positioning functions. Most of such application environments include interaction and communication scenarios, such as friend finding, virtual reality/augmented reality interactive games, etc. The purpose of the subject initiating the positioning claim is to obtain the location information of another user on the network, which requires the authorization and cooperation of the user to be positioned, and the source data required for positioning can be found in Section A.1. Positioning methods that can be used in such scenarios include ToF/ToA, TDoA, fingerprinting, and so on.

## 4.3. WIH Class

WIH, "Where is he", the main feature of such application scenarios lies in the fact that the subject initiating the positioning claim has nothing to do with the subject of the target to be measured, and even hopes to keep the target to be measured confidential, the implied implicit requirement is that the user has zero cooperation, no arithmetic requirements, but requires that the user's equipment has a certain degree of concealment and adopts the low-power consumption scheme. Such application scenarios belong to the category of passive positioning, such as target positioning and tracking, public security skynet system, key personnel and important asset monitoring, intelligent retirement community. The subject of the initiating positioning claim is generally located on the service side, and needs to complete the silent positioning of the target to be positioned at any time and under any conditions. Positioning methods that can be used in such scenarios include TDoA, fingerprinting, etc.

# 5. Establishment of 5G Small Cell

With the standardization and application of 5G systems, 5G base stations will be densely deployed, and based on the densely deployed 5G base stations will effectively improve the accuracy of indoor positioning using base station information. With the development of mobile communication networks, 5G is gradually developing from the consumer field to a wider range of vertical industries, and the deployment of low-cost and flexible 5G small base stations has become the main solution to the indoor coverage problem [4]. Due to the need to plan and deploy the transmission network and the later operation and maintenance, the investment is large; although indoor positioning technology has blossomed, the compatibility of different vendors is not high, and there is a lack of unified specification system [5]. In the face of these challenges, the combination of indoor positioning network and communication network can effectively solve these problems. With the advantage of communication network, indoor positioning information can be reused 5G small base station communication network to realize the aggregation, fusion and transmission of positioning data, avoiding the repeated deployment of positioning network [6]; through the standardization of positioning equipment and communication network interface, to promote the healthy and orderly development of indoor positioning industry. Combining indoor positioning technology with small base station communication network has natural advantages, and both of them promote each other and jointly promote the vigorous development of the industry [11].

Figure 1 shows the four-level architecture of indoor localization, which consists of localization tags, localization

base stations, transmission networks and computing application platforms. Among them, the selection of the transmission network is crucial, determining the deployment, operation and maintenance costs and the scale of the positioning system, and the transmission network needs to correspond to the selection of appropriate positioning technology, the following is a specific introduction to the positioning technology, and analyze the applicability of different technologies in the 5G small base station communication network.

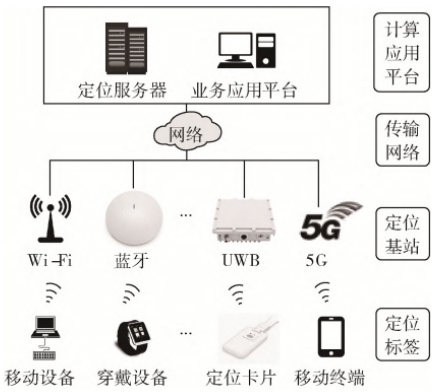



**Fig 1.** Indoor Positioning System Architecture

The fusion of indoor positioning technology and small base station communication network can provide in-depth 5G coverage, and at the same time can provide high-precision positioning capability, which is of great significance to promote the development of vertical industry. As the requirements of future positioning scenarios for positioning accuracy, coverage, equipment deployment and other aspects improve, indoor positioning technology will be further converged with the communication network, embodied in the fusion of positioning equipment and communication equipment, the fusion of positioning data and communication data, the common platform of positioning servers and communication base stations, cloud-based, integrated deployment and other aspects. In addition, the fusion of multiple positioning technologies to improve positioning accuracy is also a hot issue for future research, and in the future, 5G positioning can be combined with specialized positioning technologies to adapt to complex and changing positioning environments by utilizing the positioning advantages of different technologies to improve the positioning level.

# 6. Positioning Methods

Currently, indoor positioning systems rely on external information sources such as Bluetooth, WiFi and cellular networks. The techniques used are categorized into ranging based and non-ranging based positioning techniques. In ranging-based localization techniques, the distance from the receiving device to multiple sending devices is used to estimate the location information of the user's device. Among the non-ranging based localization techniques, fingerprint-based localization is more commonly used, which is categorized into offline and online phases. The former collects offline data extensively in indoor environments, and the format of offline data is roughly data feature-location information; the latter matches the data features collected online with the offline data, and selects the points where the offline data features are the most similar to the data features collected online for weighting to obtain the localization results. Generally speaking, the complexity of indoor environments makes it difficult for ranging and localization techniques to achieve relatively good results, while fingerprint-based localization is a more feasible indoor localization method because it can effectively record potential features of the environment when the offline fingerprint library is established.

In this section, we will focus on various mainstream technical approaches in the field of indoor positioning, discuss in detail the principles or mathematical models behind different approaches, and analyze their advantages and disadvantages.

## 6.1. ToF/ToA

The ToF (time of flight) or ToA (time of arrival) positioning method is called "time of flight" or "time of arrival" positioning method. The principle of ToA positioning method is shown in Fig. 2, which relies on the measurement of electromagnetic wave propagation time and converted to propagation distance to solve the exact position of the point to be located. The principle of ToA positioning method is shown in Figure 1, which relies on measuring the propagation time of the electromagnetic wave and converting it into the propagation distance to solve the exact location of the point to be positioned.

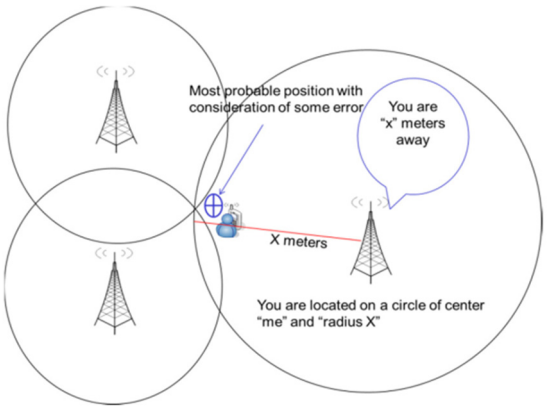



**Fig 2.** ToA Ranging

The model structure of this method is simple and easy to understand, but there are obvious drawbacks in practical applications: 1) it relies heavily on the accuracy of time synchronization, and in non-laboratory settings, the high-precision time synchronization between the node to be measured and the known node does not have the conditions for realization; 2) the mathematical model is based on the assumption of unobstructed propagation of electromagnetic waves, and when the electromagnetic wave propagation path contains refraction, reflection, or bypassing, the calculated distance will contain errors, which are also referred to as non-line-of-sight (NLOS, non-line-of-sight) errors.

## 6.2. RSSI

The principle of RSSI (received signal strength indicator) positioning method is shown in Figure 3. The principle is shown in Fig. 3. It utilizes the decay model of electromagnetic wave in space to establish the correspondence between the observed signal strength and the distance, and carry out the localization solution. The model of electromagnetic wave propagation loss in air is related to its frequency, which is generally considered to satisfy the following model:

$$L = 10\lg\left(\frac{P_{TX}}{P_{RX}}\right) = 32.45 + 20\lg f + 20lg\, r - G_{TX} - G_{RX} \quad (2)$$

Where $L$ is the power attenuation value, $P_{RX}$ is the received power, $P_{TX}$ is the transmitted power, $G_{RX}$ is the received antenna gain, $G_{TX}$ is the transmitted antenna gain and $r$ is the propagation distance. The advantage of this method lies in the simple structure, low computational complexity, and does not require any time synchronization. However, in reality, the electromagnetic wave environment is extremely complex, and the propagation process is affected by many factors such as indoor objects placement, wall blocking, and personnel movement, so the multipath effect is serious, and the localization effect is not ideal. Although it can be used with filtering algorithms or iterative algorithms to improve the accuracy, but this will increase the computational complexity and reduce the real-time localization results.

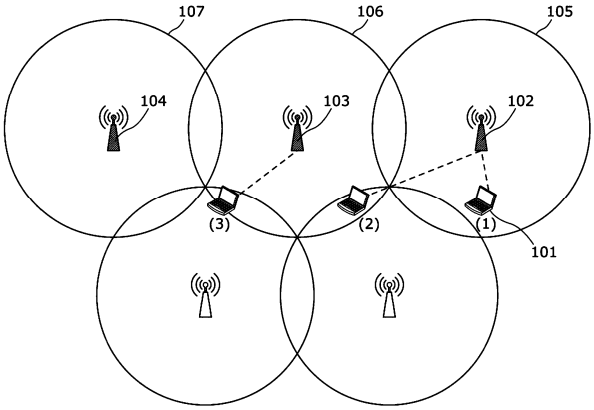



**Fig 3.** Principles of RSSI Localization Method

## 6.3. AoA

AoA (angle of arrival) positioning method, that is, based on the angle of arrival of the signal positioning method, through the array antenna to obtain the phase difference of the arrival signal, which is converted into the angle of arrival. the principle of the AoA positioning method is shown in Fig. 4, the intersection of the radial lines between multiple base stations and the point to be measured, that is, the unknown node position. The advantage of this method is that it has high accuracy, requires a small number of base stations, and does not require clock synchronization. However, AoA angle measurement requires expensive array antennas; the computational complexity of signal solving is high, which makes it difficult to support high-capacity and high-concurrency localization scenarios; in addition, the multipath effect is serious in indoor environments, and the complex decoherence algorithms further increase the computational complexity.

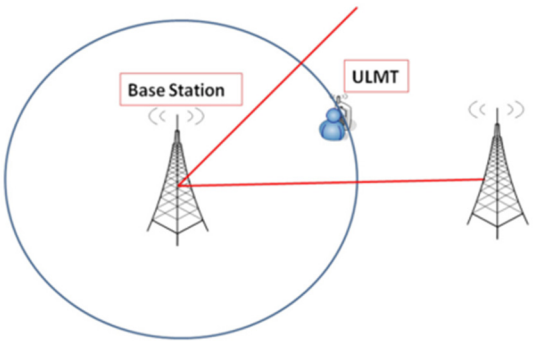



**Fig 4.** AoA Measurements

## 6.4. Fingerprint

Fingerprint localization method, i.e., the localization method based on signal fingerprint, is shown in Figure 5. This method does not require solving, and its basic idea lies in the following: in the offline localization stage, the marked point of the area to be measured is marked in advance and the environmental fingerprint information at the point is collected to establish an offline fingerprint library; in the online localization stage, the location of the point to be measured is obtained by obtaining the environmental information of the point to be measured in real time and matching it with the data items in the offline fingerprint library. One can choose RSSI, channel state information (CSI, channel state information) or other physical quantities as fingerprints [7]. However, RSSI measurements are severely attenuated by the multipath of signal propagation [8] due to strong reflection and scattering conditions indoors. Therefore, it is challenging to estimate location using RSSI measurements with various fading effects. In contrast, CSI represents the fine-grained signal propagation characteristics of wireless communication links between transceivers, which facilitates feature-based fingerprinting [9]. Therefore, in the case of a very limited number of indoor 5G BSs (e.g., less than three), the CSI fingerprinting method can achieve accurate localization results [17].

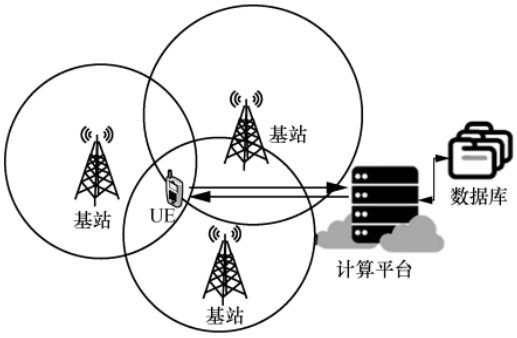



**Fig 5.** Principle of Fingerprint Localization Method

The advantages of this method are that it does not require signal solving, and it can improve the resolution accuracy of localization by more densely arranging the fingerprint collection points, and it is not affected by the NLOS error. The disadvantages of this method are that the time and labor cost of offline fingerprint acquisition is high; changes in the environment, objects, and people will interfere with the signal acquisition and matching, and it is not applicable to dynamic environments and densely populated places.

## 6.5. Positioning Integration

Nowadays, a variety of different positioning/ communication networks coexist, with different standards and technologies, resulting in different advantages and disadvantages in positioning performance, coverage, power consumption and cost, etc. 5G network facilities can provide ubiquitous connectivity for all kinds of heterogeneous networks and smart devices with different standards, so as to integrate different positioning technologies and solutions, and to realize complementarity of advantages and convergence of empowerment. The essence of "ubiquitous fusion positioning" lies in the development direction of "synergy and coexistence of multiple technologies", i.e., the future positioning network can be composite of multiple positioning/communication technologies [12].

In the future, positioning integration and convergence is the trend of 5G positioning development. Positioning integration refers to the integration of positioning functions into the communication system to achieve seamless positioning services. Convergence, on the other hand, is the fusion of different positioning technologies to improve the accuracy and reliability of positioning. The introduction of collaborative positioning technology can improve positioning accuracy and robustness through collaboration between devices, such as through position sharing and signal merging between devices.

# 7. Summary and Outlook

The development of 5G is not only an advancement of communication technology, but also further promotes the development of related vertical services [13]. 5G supports sub-meter level positioning services, which can effectively meet the positioning services in indoor scenarios. This paper focuses on analyzing the characteristics of 5G channels and providing a more detailed delineation of indoor scenarios. In addition, it also summarizes and generalizes the commonly used indoor positioning methods, which can effectively utilize the currently available information and take advantage of the inherent environmental characteristics of wireless signal propagation. The next step is to consider specific indoor environments other than wall reflections and obstacles, and explore higher accuracy indoor positioning methods to continuously optimize 5G positioning performance.

# Acknowledgments

This work was financially supported by Southwest Minzu University Graduate Innovative Research Project (Project No. YB2023530) fund.

# References

[1] “Service requirements for cyber-physical control applications in vertical domains,” 3GPP Working Group, Sophia Antipolis, France, Rep. TS 22.104 V18.3.0, 2021.

[2] Y. Ruan et al., "iPos-5G: Indoor Positioning via Commercial 5G NR CSI," in IEEE Internet of Things Journal, vol. 10, no. 10, pp. 8718-8733, 15 May15, 2023, doi: 10.1109/ JIOT. 2022.3232221.

[3] S. K. Agrawal and K. Sharma, “5G millimeter wave (mmWave) communications,” in 2016 3rd International Conference on Computing for Sustainable Global Development (INDIACom), 2016, pp. 3630–3634.

[4] Zhang Jianqiang, Feng Bo, Wang Chunyu. 5G Network Indoor Coverage Solution [J] Telecom Express, 2017 (5): 9-11.

[5] Peng Ye-shun,LI Jia-ling,XU Zhen-fei,et al. A review and outlook of Bluetooth indoor positioning technology[J]. Daily Electric Appliances,2021(12):58-64.

[6] LAOUDIAS C, MOREIRA A, KIM S, et al. A survey of enabling technologies for network localization, tracking, and navigation[J]. IEEE Communications Surveys & Tutorials, 2018, 20(4): 3607-3644.

[7] Jiang Tianrun, YIN Lu, DANG Zhongliang, et al. Research on the performance evaluation method of channel state information fingerprinting localization algorithm[J]. Navigation Positioning and Timing, 2019, 6(6): 113-118.

[8] SECO F, JIMENEZ A R, PRIETO C, et al. A survey of mathematical methods for indoor localization[C]//2009 IEEE International Symposium on Intelligent Signal Processing. Piscataway: IEEE Press, 2009: 9-14.

[9] ZAFARI F, GKELIAS A, LEUNG K K. A survey of indoor localization systems and technologies[J]. IEEE Communications Surveys & Tutorials, 2019, 21(3): 2568-2599.

[10] C. Zhang, X. Xu and A. Peng, "5G Indoor Positioning Performance Evaluation Based on Semi-Deterministic Channel Model," 2022 IEEE 10th International Conference on Information, Communication and Networks (ICICN), Zhangye, China, 2022, pp. 349-354, doi: 10.1109/ ICICN 56848. 2022. 10006618.

[11] Feng Jingxian, Yang Tao. Research and system design of indoor positioning scheme based on 5G small cell[J]. Application of Electronic Technique, 2023, 49(4): 11-15.

[12] Wang Huiqiang, GAO Kaixuan, Lv Hongwu. Review of high-precision indoor localization research and future evolution outlook[J]. Journal of Communications, 2021,42 (07): 198-210.

[13] M. Andersson, A. Lidström and G. Lindmark, "Indoor 5G Positioning using Multipath Measurements," 2023 IEEE/ION Position, Location and Navigation Symposium (PLANS), Monterey, CA, USA, 2023, pp. 1092-1098, doi: 10.1109/ PLANS53410.2023.10140035.

[14] X. Li, L. Chen, X. Zhou, Y. Ruan and Z. Liu, "Fusion of 5G Carrier Phase Ranging and 5G CSI Fingerprinting for Indoor Positioning," 2022 14th International Conference on Wireless Communications and Signal Processing (WCSP), Nanjing, China, 2022, pp. 1-5, doi: 10.1109/ WCSP 55476. 2022. 1003 9441.

[15] G. Yammine et al., "Experimental Investigation of 5G Positioning Performance Using a mmWave Measurement Setup," 2021 International Conference on Indoor Positioning and Indoor Navigation (IPIN), Lloret de Mar, Spain, 2021, pp. 1-8, doi: 10.1109/IPIN51156.2021.9662535.

[16] Z. Wang, R. Liu, Y. Zhang and Q. Liu, "A Novel Multipath Mitigation Method for 5G Positioning," 2019 15th International Wireless Communications & Mobile Computing Conference (IWCMC), Tangier, Morocco, 2019, pp. 1714-1718, doi: 10.1109/IWCMC.2019.8766655.

[17] Y. Gong and L. Zhang, "Improved K-nearest neighbor algorithm for indoor positioning using 5G channel state information," 2021 IEEE 5th Information Technology, Networking, Electronic and Automation Control Conference (ITNEC), Xi'an, China, 2021, pp. 333-337, doi: 10.1109/ ITN EC52019.2021.9587088. a/.