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Research Article

A Pseudolite Indoor Wide-Area Networking Technology Based on Signal Multilevel Features

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At present, pseudosatellite navigation and positioning technology is the only positioning technology compatible with GNSS navigation signals and applied to indoors. This technology can realize continuous indoor and outdoor positioning services for mobile terminals and dedicated terminals. At the same time, the indoor application of pseudolite technology also faces some problems. Aiming at the large-area networking problem of pseudolites in indoor space, this paper uses the existing indoor array pseudolite technology to propose a technique for constructing a network using the characteristics of pseudolite signals in indoor space. By making full use of the signal's multiple access classification characteristics and the signal's Doppler, interstation delay, and other characteristics, a multilevel grid segmentation and networking scheme for indoor space based on pseudolites is realized. This method combines the existing experimental foundation and experience accumulation, has the feasibility of realizing large-area networking indoors, can solve the problems faced in the current indoor pseudolite networking process, and provides guarantee for the application of pseudolite networking in indoor environments.

1. Introduction

Indoor space usually refers to all enclosed or semienclosed facilities and places. At present, with the rapid development of computer and Internet of Things technology, the demand for positioning technology is not only limited to outdoor high-precision navigation and positioning, but also it is required in fields such as in logistics and transportation, environmental monitoring, mine personnel positioning, earthquake and fire rescue personnel, and shopping malls.

There are also many positioning systems for indoor spaces on the market, but these systems rely on multiple types of sensors (such as sensors for sound, magnetic field strength, and temperature) to measure data. And before the measurement, a large number of wireless sensors must be deployed in the measurement environment as measurement nodes. Through the close cooperation between these sensors, the data to be measured is monitored, and the measured data is transmitted to the data processing center for calculation. Sensors have evolved from a single way of sensing before to now have two sensing modes that not only have a fixed position but also a moving position. For a sensor node with a moving location, if there is only sensor information but no location information, then the sensor node has no meaning. Therefore, the precise positioning of wireless sensors has become a key technical issue in the development of Internet of Things technology.

Pseudolite positioning technology can effectively solve the above-mentioned positioning demand problem. Pseudolite is a low-cost, easy-to-deploy navigation and positioning platform. When the visibility of some navigation satellites is reduced and satellite navigation signals are interfered, navigation services can be provided to users in specific areas by deploying pseudolites when the performance of satellite navigation services is degraded. Pseudolite positioning system has the following advantages: (1) strong anti-interference ability: pseudolites are generally located near the receiver, so the strength of the navigation signal received by the receiver is relatively high, so the pseudolites have stronger antijamming capabilities than GNSS satellites; (2) flexible networking: the pseudolite positioning system can select the location and number of pseudolites in the positioning process according to the positioning needs and environment; and (3) the equipment is simple and the cost is low. Compared with the current GNSS positioning system, the pseudolite equipment is relatively simple and low in cost. Therefore, studying the technology of pseudolites for indoor spatial positioning is a feasible and widely applicable technology.

In summary, the pseudolite positioning system is not only a supplement to the satellite navigation and positioning system to improve positioning accuracy but also independent networking to achieve separate positioning. Pseudolite positioning technology is one of the effective ways to solve the existing problems of indoor space positioning. Pseudolite positioning technology usually encounters positioning accuracy, signal multipath, and pseudolite networking when applied indoors. Here, the research is mainly carried out from the perspective of indoor networking applications of pseudolites. Pseudolite indoor networking mainly involves two aspects of pseudolite network time synchronization and pseudolite indoor geometric distribution. Time synchronization between pseudolites not only requires high accuracy, basically at the picosecond level, but also requires high real-time performance. The size of the precision factor is directly related to the geometric distribution of the pseudolites and has a certain relationship with the horizontal positioning accuracy and vertical positioning accuracy of the pseudolites.

At present, a relatively mature ground-based navigation system called Locata is developed for Australia's Locata company. The system is constructed by independent networking of synchronization signal transceivers (LocataLites). After LocataLites are arranged in fixed coordinates, between different LocataLites Receive and send internal time synchronization signals to each other, complete LocataNet autonomous networking, and achieve nanosecond time synchronization within the network through TimeLoc technology. The Southwest Jiaotong University and National University of Defense Technology both use the Locata system to complete the network research of pseudolites.

The team of Liu et al. [1] and Xue and Wang [2] of the Hunan University used the visual domain analysis technology to determine the signal coverage of the system from the perspective of pseudolite system deployment and used a multimatrix multiplication-weighted level precision factor calculation method to measure the geometric layout of the base station. The NSGA-II algorithm is used to solve the nondominated optimal solution set of the two optimization goals. The Xi'an University of Science and Technology and Wuhan University of Technology analyzed the layout of pseudolites from the perspective of the influence of different satellite array networks on the precision factor. Meng [3] of the People's Liberation Army Information Engineering University conducted research on the network configuration of pseudolites, analyzed the line-of-sight range and DOP characteristics of air and ground pseudolites, based on the DOP characteristics, and gave a network scheme for different numbers of pseudolites. Since 2005, the Northwestern Polytechnical University [4] has done some preliminary research on the combined positioning of pseudolites and Beidou. Its research mainly lies in the layout of pseudolites and Beidou. The literature applied Lagrangian method and verified some theories of pseudolite layout through simulation analysis. He [5] of the University of Electronic Science and Technology of China conducted research on key technologies of pseudo-satellite navigation based on adjacent space networking nodes. The geometric layout of the pseudolite constellation is studied, the influence of the geometric precision factor GDOP on the positioning error is analyzed, and the relationship between the altitude and azimuth angle changes of the pseudolite and the GDOP is obtained through simulation. The team [6] of Zeng et al. of the Institute of Optoelectronics of the Chinese Academy of Sciences proposed a route planning algorithm for the network deployment of space-based pseudolites from the initial position to the target position in order to solve the problem of space-based pseudolites based on adjacent space airships.

The multimode pseudolite self-organizing network time synchronization system researched by Jia [7] of the Xidian University realizes the satellite-ground time synchronization. The time synchronization accuracy of the Beidou navigation system is better than 38 ns, and the time synchronization accuracy of the GPS navigation system is better than 32 ns. The time synchronization accuracy between pseudolites is better than 0.2 ns, and the system has a self-organizing network function, which supports the implementation of pseudolite self-organizing network engineering and has good engineering application value. Based on the indoor positioning signal networking theory, Xiao and Fujii et al.'s team [8, 9] from the Beijing University of Posts and Telecommunications analyzed and compared several indoor supplementary system networking methods, studied the ultrawideband hierarchical networking model, proposed an ultrawide hierarchical networking plan for the indoor supplementary system, solved the problem of indoor positioning signal networking restricted by indoor building space, and analyzed and studied the method of planet-ground time synchronization in traditional satellite navigation systems. Aiming at the short distance of indoor positioning synchronization nodes and high synchronization accuracy requirements, a two-way signal-based UWB was used. Comparing the time synchronization technology and applying this technology to the TC-OFDM indoor positioning signal time synchronization process and error analysis, the experimental results show that the synchronization accuracy can reach 2 ns. Lee et al. [10] and Gu et al. [11] analyzed the clock synchronization of pseudolites from the perspective of clock sources; Wang et al., Ma et al., Wang et al., and Xue et al.'s team [12–15] studied the issue of pseudolite timing from the perspective of combining with GNSS.

The existing research on pseudolite networking technology is oriented to outdoor environments. On the one hand, this type of research considers how to improve the DOP value. On the other hand, due to the open outdoor environment, multiple time synchronization methods can be given; on the other hand, researchers in this environment are more concerned about how to achieve accurate time synchronization of indoor pseudolite networks. Although the corresponding synchronization methods have been given above, there are still some problems in realizing the strict time synchronization of pseudolite networks when faced with a complex gridded nonline-of-sight indoor environment. The current pseudolite indoor networking technology is affected by factors such as the number of ranging codes and spatial networking synchronization, and the general networking space is limited. A truly generalizable application network model should have a new network architecture with flexibility, scalability, and low-cost and efficient networking to achieve the comprehensive goal of taking into account positioning accuracy, seamless coverage, and low cost.

Therefore, the development of regional networking technology for pseudolites with multiple signal characteristics is a key technology and research focus here. In response to this problem, the main work of this article is as follows: in the second section, we introduce the existing pseudolite technology foundation, the concept of pseudolite feature information, and the indoor space division standard involved in this article. In the third section, we introduce the application of each feature information in the networking; in the fourth section, we give the analysis steps of the indoor network optimization station layout from the perspective of geometric distribution; in the fifth section, we use the pseudolite networking method and the standard of space division giving the networking scheme in each scenario. Finally, on the basis of the existing results, we summarize the technical advantages of the current method and give the follow-up research directions.

2. System Overview

2.1. Introduction of Pseudolites. In the previous research process, the principle of pseudolite [16–25] has been briefly introduced. The pseudolite generates a local intermediate frequency signal under the control of the same clock. Because the signal has the same time-frequency characteristics and hardware delay characteristics, when the base station broadcasting multiple pseudolite signals at the same time, the time before each pseudolite signal is strictly the same, and the time-frequency characteristics are also strictly the same. On this basis, we found that in a limited area, the local location network composed of multiple signals from a single base station is strictly time synchronized; the working principle is shown in Figure 1. At the same time, according to the precision factor, by adjusting the position of the multichannel signal transmitting antenna, the optimal DOP distribution in the limited area is completed.

2.2. Introduction of Characteristic Information

2.2.1. Signal Multiple Access Characteristics

(1) Time Division Multiple Access (TDMA). TDMA divides time into periodic frames, and each frame is divided into several time slots to send signals to users. Under the condition of meeting the timing and synchronization, the user can receive the signal of each base station in each time slot without mixing. When using pseudolite signals for positioning, we usually use TDMA to solve the problem of near-far effects of signals.

The pseudolite pulse pattern mainly refers to a pulse method recommended by the RTCM SC-104 committee. This method uses some reserved codes in the GPS C/A code group to design the pulse scheme. This design can ensure that the receiver hardware receive satellite and pseudolite signals at the same time with minimal changes. In the scheme, each pulse lasts for 1/11 ms; that is, 93 chips are sent per pulse, and one pulse is sent every millisecond. But every time the tenth pulse is reached, the tenth and eleventh pulses will be sent at the same time to ensure that the average duty cycle of the pulse is 10%. Between each cycle, the pulse position changes over 11 possible time slots, while the 11 pulse positions also change between each data bit. In this way, all possible pulse positions complete a cycle within 200 ms, so as to eliminate the influence of overlap as much as possible. In the follow-up research, it is found that the random time slot allocation is more conducive to the reception of the receiver terminal. Here, in combination with practical applications, the design will be based on a maximum of 10 time slots and a minimum of 6 time slots.

(2) Code Division Multiple Access (CDMA). The CDMA system is a communication system based on code division technology and multiple access technology. The system assigns a specific address code to each user. The address codes are quasiorthogonal to each other, so that they can overlap in time, space, and frequency; the information data that needs to be transmitted with a certain signal bandwidth is modulated with a pseudorandom code with a bandwidth much greater than the signal bandwidth, so that the bandwidth of the original data signal is expanded, and the receiving end performs a reverse process and despreads, which enhances the ability of anti-interference. Our general GPS, Galileo, and Beidou navigation signals use CDMA characteristics to realize the recognition function of different satellites under the same frequency.

(3) Frequency Division Multiple Access (FDMA). FDMA distinguishes the channels of different users with different frequencies, that is, uses different carrier frequencies, selects signals through filters, and suppresses useless interference, and each channel can be used simultaneously in time. Based on this, the GLONASS system realizes the identification of different satellites.

2.2.2. Time Delay Characteristics of Pseudolite Network. In the traditional time synchronization networking process, more consideration is how to achieve precise synchronization between various base stations. The smaller the delay, the better. However, our pseudolite base station is a homogenous multisignal transmission. Before the signal in the same area, it has strict time synchronization and time-frequency characteristics. When the base station and the

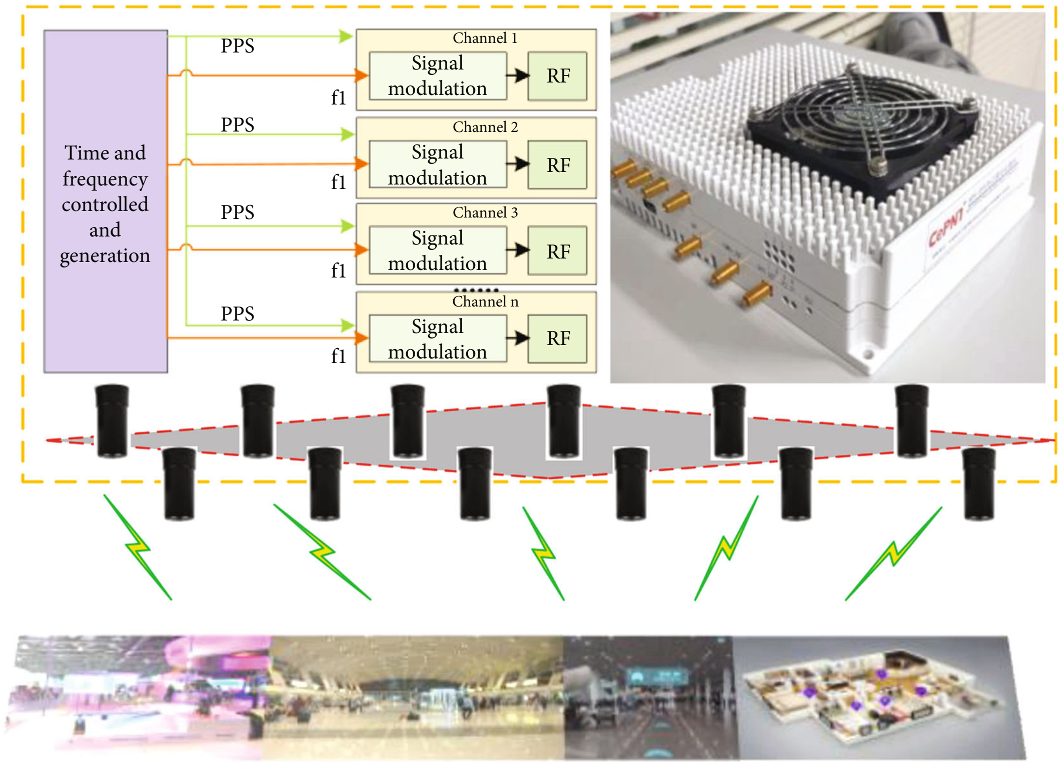

Figure 1: Signal transmission base station working principle.

base station are networked, there will definitely be a certain delay difference. Here, if we want to achieve strict synchronization between base stations, the problems exposed by the time synchronization part in the previous networking technology research will still exist. Here, we consider backward thinking. Since synchronization is difficult to achieve, we can regard the delay difference as a characteristic of the signal and distinguish the areas covered by different base stations through the delay difference, so that we can not only solve the synchronization problem but also increase the available features for indoor positioning.

2.2.3. Doppler Characteristics of the Signal. Pseudolite signals are exactly analog satellite signals. In the process of receiving pseudolite signals by the receiver, due to the clock difference and clock drift, the receiver will have a certain value of Doppler drift even in the case of static positioning. Especially in the process of Doppler velocity measurement, this value directly affects the estimation process of receiver velocity. Therefore, in the process of pseudolite positioning, we are more concerned about how to eliminate the effects of clock offset and clock drift. But in the test, it is found that the characteristics of different receivers are different, and the different pseudolite base stations are also different. Therefore, the elimination of this value is generally eliminated by means of single difference between channels. It is believed here that if in the process of networking, the time-frequency consistency between pseudolite stations can be solved through time-frequency networking; then if we introduce a fixed Doppler frequency shift feature in the signal layer, then the feature value can be considered either it is known and can be eliminated. It can also be used as a typical feature information for area recognition.

2.2.4. Signal Spatial Characteristics. The most typical feature of indoor space is the complex environment. The existing indoor space division is generally divided into large-scale space, medium-scale space, and small-scale space, but there is no specific quantification of what indoor space environment each definition corresponds to. Under normal circumstances, we regard bedroom space and office space as small-scale space and Olympic venues, stadiums, and other spaces as large-scale space, and there is a space similar to a corridor scene. In the next section, we will combine the actual measurement experience to give a quantitative standard for dividing the indoor space of pseudolite. However, because the positioning in the indoor environment is usually based on the positioning in the signal line-of-sight environment, we can use the directional characteristics of the transmitting antenna and the physical division characteristics of the space and at the same time use the pseudolite signal to realize the indoor segmentation.

2.3. Types of Indoor Scenes. This section combines the experience of application demonstrations in shopping malls, airports, and Olympic venues and subdivides traditional large-scale and small-scale spaces into three types: multizone space, room-type space, and corridor-type space. At the same time, the standard of quantification of the three types of space is given. The details are shown in Table 1. Of course, due to the complexity and diversity of indoor space, it is difficult to avoid involving some areas close to the boundary

Table 1: Quantitative segmentation of indoor space scenes.

Name	Partition conditions	Application scenarios
Multizone space	Vertical height > 5 m Horizontal space area ≥ 100 m^2, length and width are ≥10 m	Mainly include application scenarios of large-scale physical spaces such as Olympic stadiums, airports, and railway stations.
Room space	(1) Horizontal space area ≤ 25 m^2, length and width are ≥5 m (2) Vertical height ≤ 5 m; the spatial scale is a combined space of multiple smallest room-type spaces (3) The area near concrete, metal, and other reflective walls of 2-3 meters in a multizone space	Room-type spaces mainly include application scenarios with small physical space such as elevators, offices, and toilets.
Corridor space	The ratio of horizontal space length to width ≥ 5	Corridor space mainly includes typical application scenarios such as roadways, pipe corridors, and tunnels.

value. Here, we can refer to the following table and choose flexibly according to the indoor positioning service requirements of pseudolite, which will not be discussed in detail here.

3. Application of Characteristic Information in Networking

In the above section, we introduced the existing indoor pseudolite local area networking principles in detail. This method has obvious advantages in the indoor single-area networking process, that is, strict synchronization of signals can be achieved in a single area. But at the same time, there is also a problem in the later application and promotion, that is, how to realize the multiregional networking of indoor pseudolite when facing the application of indoor large-area pseudolite positioning. Obviously, there is an upper limit on the number of multichannel signals that a single base station can output, and in the indoor environment laying process, it is impossible to complete the laying of the entire indoor large area with N cables. The most direct reason is that there are many problems with the entire network. On the other hand, we need to take into account the link loss of the signal and the hardware isolation of the channel signal at the same time. The general satellite number of the navigation signal is limited, and the single signal may have errors when used in multiple areas. Other issues were also identified.

Therefore, we will make full use of the existing foundations in Section 2.1 and the signal characteristics of Section 2.2, combined with the characteristics of TDMA, CDMA, FDMA, and space division, to propose a new large-area networking scheme suitable for indoor spaces. For the convenience of introduction, the application of single feature in networking will be introduced in the following subsections. In the later large-area networking, users can combine freely in combination with actual scenes to achieve the grid of the smallest unit of the indoor environment. Among them, TDMA, CDMA, and FDMA technologies are not affected by regions during the indoor networking of pseudolites, but the rules in the following subsections must be followed. During the application of interstation delay and Doppler characteristics, its application is limited to interstation.

3.1. Application of TDMA in Networking. When indoor space needs to consider the problem of near and far effects between signals, TDMA can solve this problem well, but the allocation of pulse time slots is usually limited. Therefore, in a large area network, there are multiple signals that are transmitted in the same time slot. Inevitably, in order to reduce signal interference as much as possible, we usually follow certain principles. The time slots of the same base station in the same area of the ad hoc network are different. Multiarea networking of different base stations ensures that the distance between different signals in the same time slot is as far as possible. The application of TDMA in pseudolite networking is shown in Figure 2.

3.2. Application of CDMA in Networking. CDMA technology has been introduced in the previous section, and it is applied to the identification of GNSS satellites in an outdoor environment. However, in an indoor environment, due to the limitations of indoor space, if all pseudolite signals are broadcast in a unified area, multiple access interference will be very obvious. According to actual test experience, it is generally better to broadcast 6-8 pseudolite signals in the same area. Therefore, using existing satellite numbers, pseudolites can complete 4-5 groups of indoor space segmentation. Of course, if it is in small-scale space and corridor space, through the division of directional antennas and physical space, more indoor spaces can be achieved. At the same time, it can realize the segmentation, identification and positioning of more indoor spaces. The application of CDMA in pseudolite networking is shown in Figure 3.

3.3. Application of FDMA in Networking. FDMA technology can realize the identification of different satellite numbers. Here, in the application of pseudolite indoor positioning technology, FDMA technology achieves better compatibility with GNSS system, so as to realize the universal application of commercial receiving terminals in indoor and outdoor environments. The frequency division here, to be precise, uses the multifrequency characteristics of the GNSS system and realizes the purpose of pseudolite indoor positioning by using multifrequency navigation signals. Multifrequency signals are relatively flexible in indoor applications. They can be broadcast in the same area to increase the number

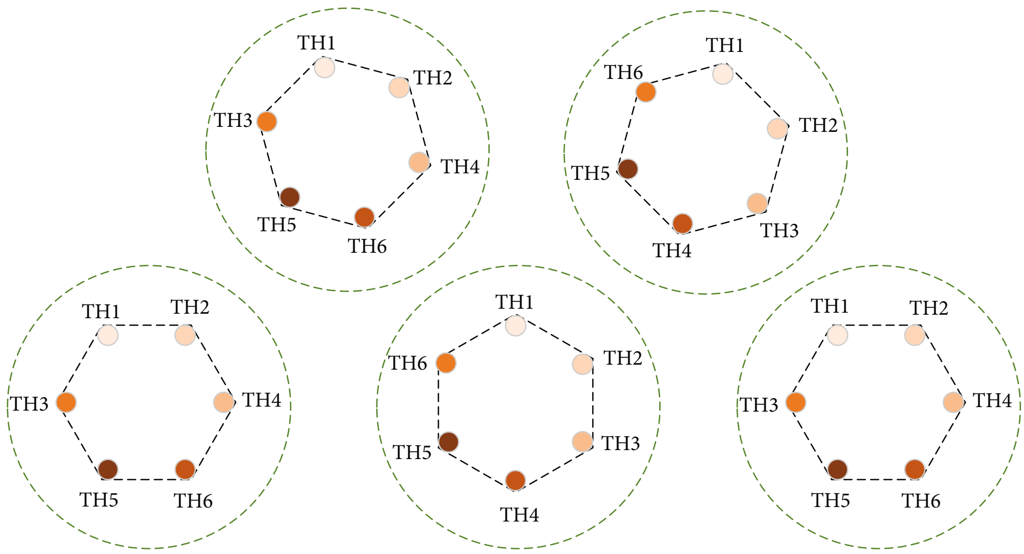

Figure 2: Application of TDMA in pseudolite network.

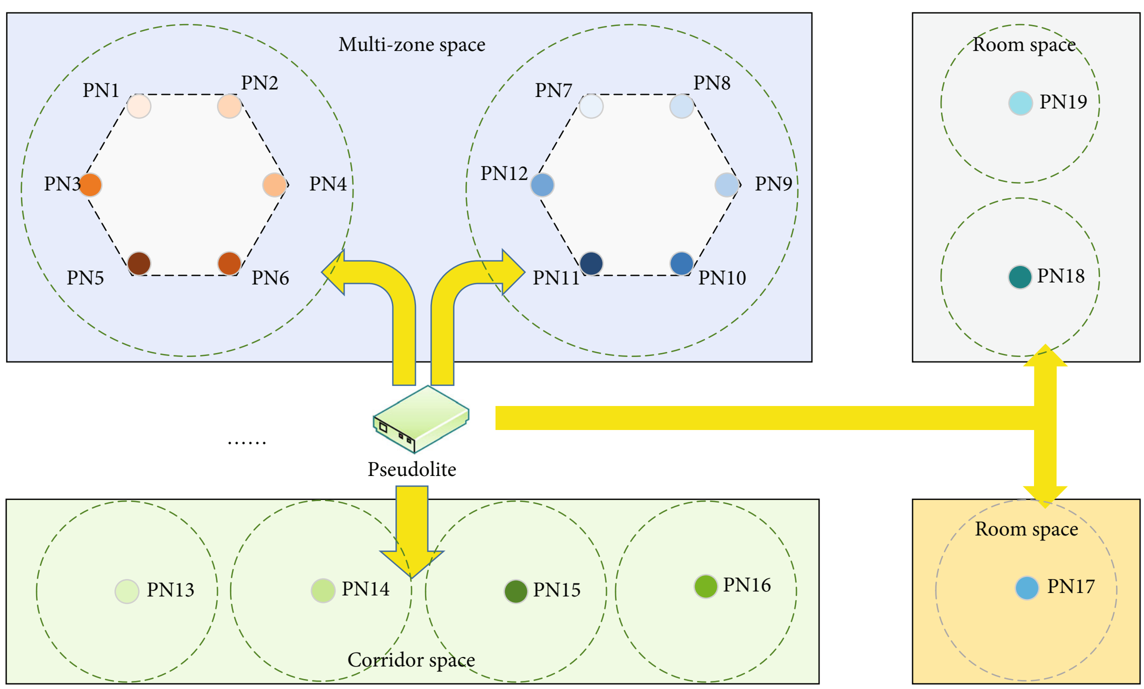

Figure 3: Application of CDMA in pseudolite network.

of visible pseudolites in the same area and improve positioning accuracy; they can also be broadcasted in different areas to recognize different indoor spaces.

3.4. Application of Interstation in Networking. The application of the interstation delay characteristic is mainly the application of the definition characteristic of the redundancy of the receiver's original observable variables. Normally, the variable type defined by the receiver is signed integer data, but the original observation data output by the commercial receiver is 70 ms. For the distance between the left and right speed of light, the delay between the base station and the base station is within a certain range, and the original observation output of the receiver is guaranteed to be between $\pm 2^{\wedge 31}$; we can use the data for positioning calculation without calculating the delay. This feature is mainly used between different base stations with the same pseudolite signal characteristics. As shown in Figure 4, we can use this feature to realize the application of pseudolite base stations with the same signal feature in different floor spaces and the application of relatively independent spaces on the same floor.

3.5. Application of Doppler in Networking. The application of Doppler characteristics of pseudolite signals should fully

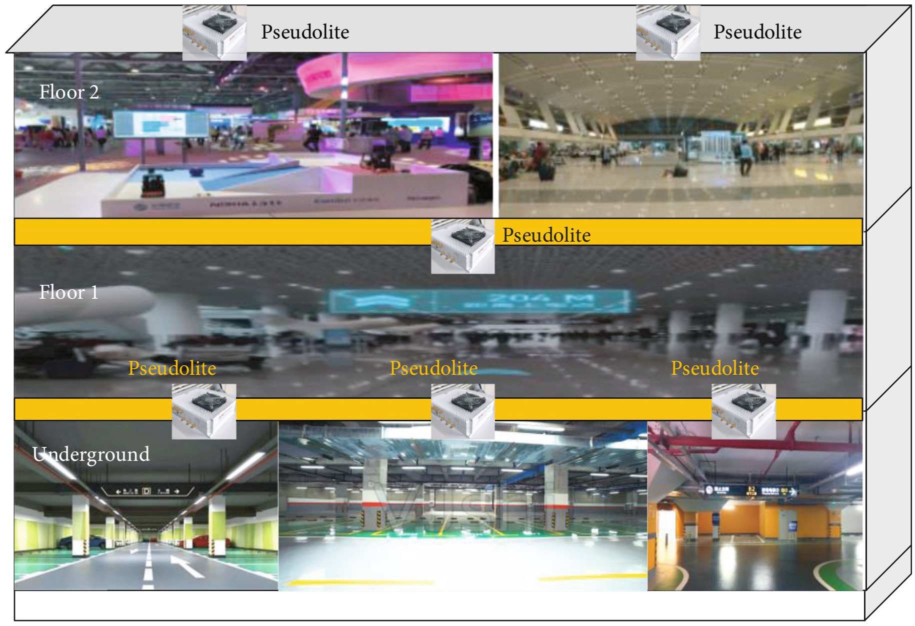

Figure 4: Application of time delay characteristics in interstation networking.

consider the dynamic receiving characteristics of the receiver. It is assumed here that the Doppler value introduced by the maximum speed of the indoor environment is dop, the dop step value between the base stations is Δd, assume that the dynamic characteristic introduced according to the clock difference of the receiver is d_m, and the characteristic value N between the regions can be introduced according to the Doppler characteristic.

$$N = \frac{\mathrm{dop} - d_m}{\Delta d}. \tag{1}$$

The application of this feature is similar to Section 3.3, and it mainly solves the spatial multiplexing problem of pseudolite base stations with the same signal feature. By distinguishing these features, a more refined spatial segmentation of the interior can be achieved.

4. Optimized Deployment of Base Station Networking

The previous section mainly used signal characteristics to provide a more flexible way for indoor pseudolite networking, which fundamentally solved the problem of indoor space grid segmentation and time synchronization.

This section will further introduce a genetic algorithm-based indoor space networking optimization scheme from the perspective of geometric distribution. Genetic algorithm is a global optimization adaptive probability search algorithm. It uses a group search technology to impose a series of operations such as selection, crossover, and mutation on the current group to produce a new generation of groups and gradually evolve the group to contain or approach the most state of excellent solutions. Especially for the optimization of large-scale, highly nonlinear systems, and objective functions without analytic expressions, genetic algorithms show more unique and superior performance than other traditional optimization algorithms. Specific steps are shown in Figure 5.

Step 1. Import indoor 3D spatial map information (DEM data).

Step 2. For spatial grid segmentation, the entire test site space is divided into n areas, each area is further divided into a number of spatial grids, and each grid represents a possible position of the pseudolite base station in the area; then, each base station is searched in these grids s position. Since there are n objects to be optimized, the location of each base station needs to be described by 3 parameters. Therefore, the optimization involves a total of $3 * n$ parameters, and the search space is quite large.

Step 3. Take the position of n pseudolite base stations as the optimization object, and take the geometric performance HDOP of the base station as the optimization target. The basic principles of the optimization design of station deployment based on genetic algorithm are as follows: (1) select a randomly distributed sample group and calculate separately. They calculate the fitness of each group based on the HDOP value of the target in the coverage area and then calculate the fitness of each group through appropriate weighted combination of these performance parameters. (2) Iterative search is performed; that is, a new population is generated through genetic operations such as selection, crossover, and mutation. Repeat calculation of its fitness. (3) Get samples that meet the index and search iteration to the preset maximum termination algebra, then it is determined that the optimal or approximately optimal solution is obtained, and the iteration is terminated. The specific process is shown in Figure 6.

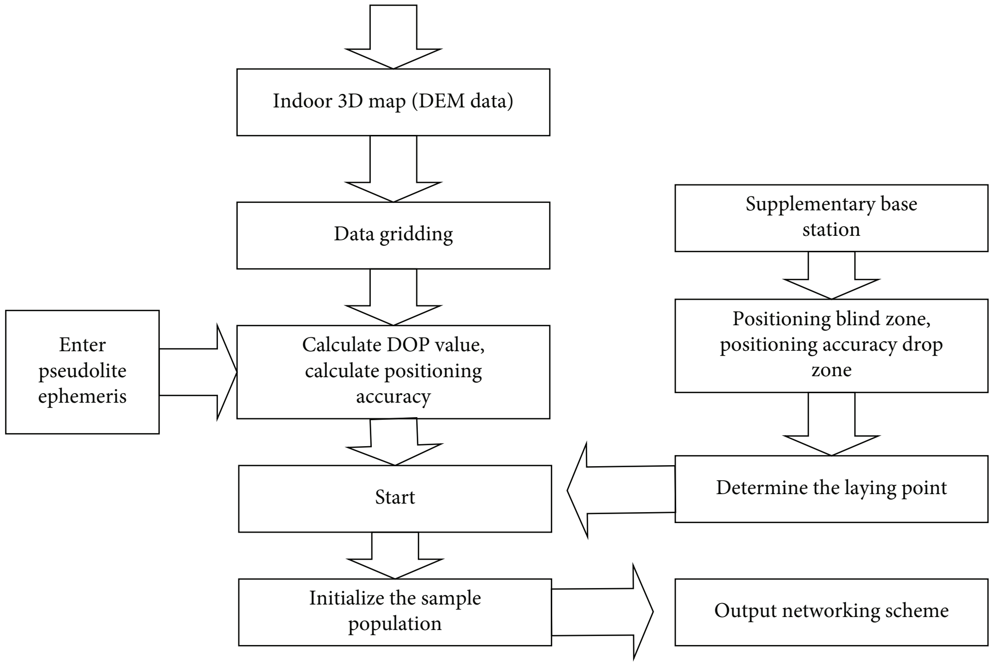

Figure 5: Base station networking optimization process.

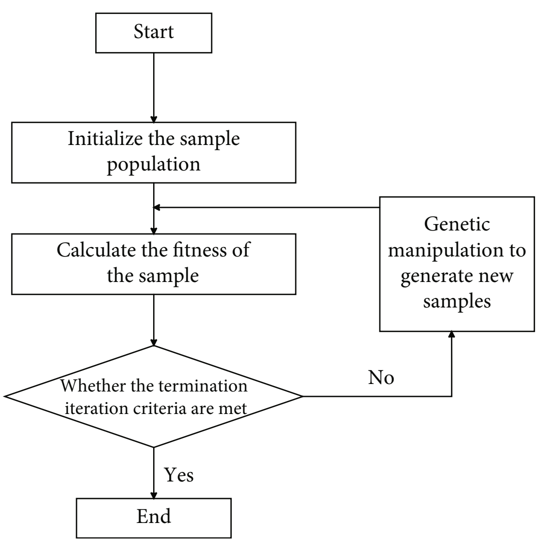

Figure 6: The principle of base station networking based on genetic algorithm.

4.1. Encoding. Assume that the deployment site size of the pseudolite base station positioning network is SS, and the number of base stations is taken as 6. The test site is divided into 6 areas, each subarea is SubSS, and each area is divided into three-dimensional space grids. Taking the center of the site as the origin of the coordinates, the grid points represented by the three-dimensional coordinates mi, ni, and li are generated in the 6 areas as the site of the station in the area, and the site is connected in sequence to form the corresponding gene of the site. Different combinations of grid points in all different regions constitute the entire search space.

4.2. Generation of the Initial Population. In the 6 three-dimensional grid areas, 6 points are randomly selected as the base station deployment positions, the 6 base station positions constitute a sample, and the combination of multiple samples constitutes a sample group.

4.3. Fitness Assessment. Taking into account the line-of-sight of the base station, calculate the HDOP value in the coverage area. Combine the HDOP of 12 fixed target points to give the fitness index of the base station deployment.

According to the six observation equations, through the expansion of the first-order Taylor formula, the coefficient matrix A can be given as

$$A = \begin{bmatrix} h_{00}\, h_{01}\, h_{02}\, 1 \\ h_{10} & h_{11} & h_{12} & 1 \\ \vdots & \vdots & \vdots & \vdots \\ h_{50} & h_{51} & h_{52} & 1 \end{bmatrix}. \quad (2)$$

Here, A matrix represents the horizon coordinate system; the equation coefficient matrix N is

$$N = \left[A^T A\right]^{-1}. \quad (3)$$

The horizontal precision factor HDOP calculation formula is

$$\mathrm{HDOP} = \sqrt{N_{00} + N_{11}}. \quad (4)$$

In combination with the threshold design requirements of HDOP, the fitness F is expressed as a decreasing function of HDOP within this range.

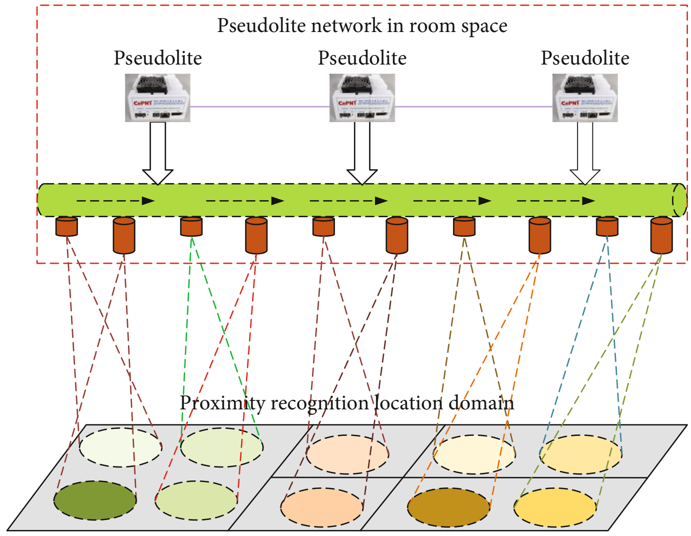

Figure 7: Networking solution for room space proximity positioning.

4.4. Choose. The selection operation is based on the evaluation of the individual's fitness.

The most commonly used proportional selection method (proportional model) is used as the selection operator. It is a playback-style random sampling method. The basic idea is that the probability of each individual being selected is proportional to its fitness.

Suppose the size of the population is M and the fitness of individual i is F_i; then, the probability of this individual being selected is

$$P_i = \frac{F_i}{\sum_{i=1}^{M} F_1}. \quad (5)$$

4.5. Cross. Before the crossover operation, the individuals in the group must be paired. At present, the most commonly used pairing strategy is random pairing; that is, M individuals in the group are formed into a $M/2$ paired individual group in a random manner, and the crossover operation is performed between two pairs of these paired individual groups. The design consideration of the crossover operator includes two aspects: determining the position of the crossover point and performing partial gene exchange.

The most basic single-point crossover method is used as the crossover operator. The method is as follows: for each pair of individual groups, randomly set the position after a certain locus as the crossover point, and then according to the preset crossover probability Pc (generally taking the value between 0.4 and 0.99), the genes of two individuals are exchanged at the intersection point, resulting in two new individuals.

4.6. Variation. The design considerations of mutation operators also include two aspects: determining the location of mutation points and performing gene value replacement. The basic mutation (simple mutation) operator is the simplest and most basic mutation operation operator. Its basic process is as follows: for each locus in the individual, according to the predetermined mutation probability Pm (generally the value is 0.0001~0.1), designate it as a mutation point; for each designated mutation point, invert its gene value to generate a new individual.

5. Typical Application Scenarios and Positioning Networking Solutions

5.1. Types of Indoor Scenes. Combining the above three typical scenarios and environmental applicability, the positioning networking solutions in the three scenarios are given here.

5.1.1. Networking Solution for Room Space Proximity Positioning. This positioning method is suitable for places with low positioning accuracy, such as the recognition of the parking lot partition area and the recognition of the merchandise sales area of the shopping malls. When the user receives a pseudolite signal, the user can know his approximate location and inform the user of the destination. The relative direction to the current location guides the user in the next path decision-making. The details are shown in Figure 7.

5.1.2. Networking Solution for Corridor Space Proximity Positioning. This positioning method mainly solves the user positioning problem in a corridor environment. Since the left and right are restricted by the space environment, the positioning in this environment is actually a one-dimensional positioning in the radial direction. When the user receives a pseudolite signal, the mobile phone determines the current location of the area according to the position information and signal strength changes broadcast by the data control center. At the same time, combined with the assistance of the mobile phone's MEMS sensor, it can realize continuous positioning in a narrow and long environment. The details are shown in Figure 8.

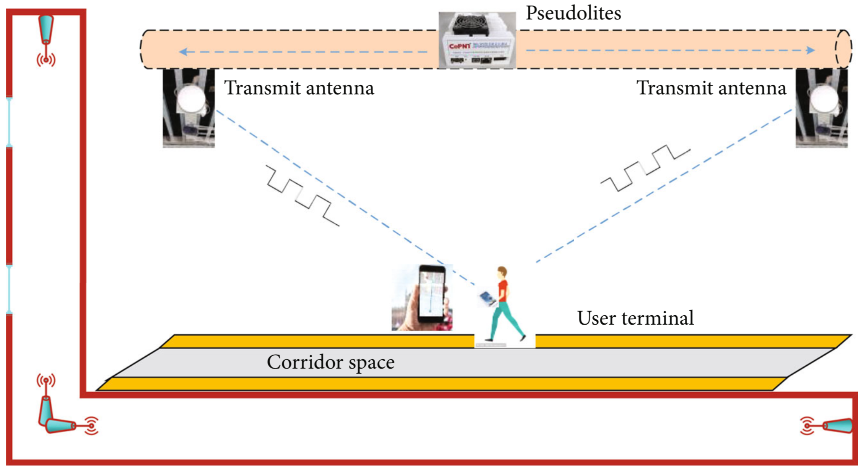

Figure 8: Networking solution for corridor space positioning.

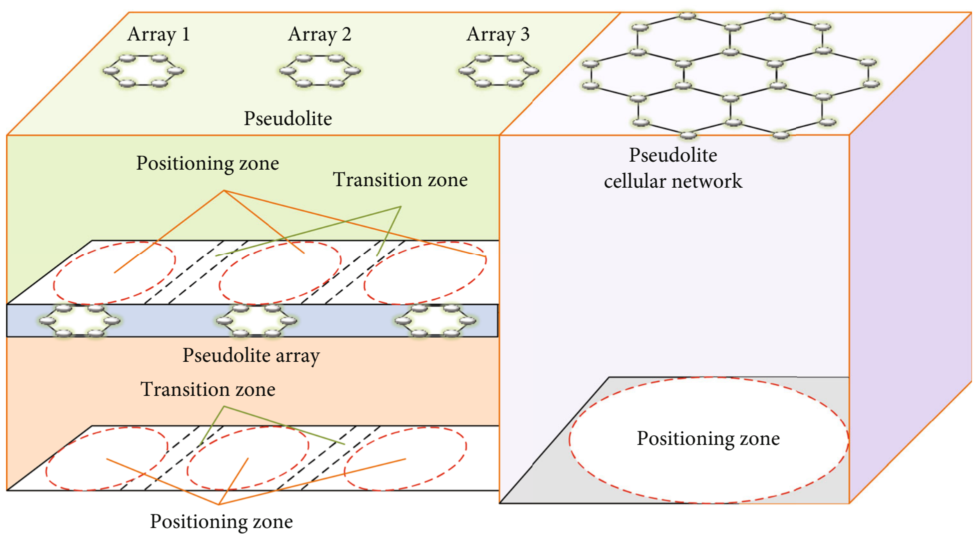

Figure 9: Networking solution for multizone space positioning.

5.1.3. Networking Solution for Multizone Space Positioning. This method mainly solves the problem of high-precision accuracy in the indoor environment of public terminals and dedicated terminals. There are two main methods: one is refined regional positioning based on the raw data of instantaneous pseudolite signals. This method first determines the current location area through signal recognition and then uses the instantaneous raw data at the output terminal, including information such as carrier-to-noise ratio, pseudorange, carrier phase, and Doppler, to determine the user's directional position in the current area to achieve indoor positioning of 1-3 meters; one is based on continuous stability. The carrier phase-differential positioning of the raw data of pseudolites is mainly based on the phase ranging algorithm to achieve submeter positioning in the indoor environment. Its networking mode is shown in the figure below. The networking method is as follows. For the conventional multizone space, we choose the array positioning method, as shown on the left side of Figure 9; for the super large indoor multizone space, we adopt the cellular pseudolite array networking method to achieve regional location services, as shown on the right side of Figure 9.

5.2. Precautions for Pseudolite Networking

(1) The maximum delay difference of the network between pseudolite base stations meets the redundancy of the original data output variables of the receiving terminal

(2) Customize a dedicated directional antenna according to the space environment to reduce indoor signal multipath and multiple access interference

(3) The layout of the pseudolite base station should follow the principle of the highest vertical dimension in a single area and the most open position in the horizontal dimension

Table 2: Coverage for pseudolite networking.

Service form	Service index	Coverage indicator
Single pseudolite signal	Signal coverage	100% coverage
	Signal available coverage	100% coverage
	Signal reliability positioning coverage	100% coverage
Double pseudolite signal	Signal coverage	100% coverage
	Signal available coverage	100% coverage
	Signal reliability positioning coverage	100% coverage
Array pseudolite signal	Signal coverage	Single-array pseudolite coverage radius R: $H \leq 40$; where R is the height of pseudolite, the unit is meter.
	Signal available coverage	Single-array pseudolite coverage radius R: $H \leq 40$; where R is the height of pseudolite, the unit is meter.
	Signal reliability positioning coverage	Single-array pseudolite coverage radius R: $H \leq 40$; where R is the height of pseudolite, the unit is meter.

(4) The high-precision continuous positioning area meets the core area 2-3 meters away from the concrete and metal walls

5.3. Coverage for Pseudolite Networking. The coverage of pseudolite network includes three types: (1) single pseudolite signal coverage for room-type space, (2) double satellite coverage for corridor-type space, and (3) array pseudolite coverage for multizone space. The coverage characteristics of the three types of pseudolite networks are shown in Table 2.

6. Conclusions

In view of the current indoor pseudolite networking application problem, there is currently no feasible solution. Based on the existing array pseudolite base station technology and combining the existing signal characteristics of the pseudolite, this paper proposes a multifeatured pseudolite indoor space networking and positioning technology. This technology has the following advantages: (1) solve the traditional indoor networking time synchronization problem, convert the past how to correct the time delay error into how to use the time delay error, and solve the complicated indoor calibration work and delay error problems. (2) Solve the problem based on pseudolite. Compared with the indoor proximity positioning of the Japanese IMES system, the spatial segmentation of signal features provides richer signal features. The space can be more refined segmentation, thereby further improving the accuracy of indoor proximity positioning. (3) It provides a richer networking solution for the indoor applications of pseudolite, which meets the application requirements of different scale spaces and at the same time solves the application requirements of terminals with different positioning levels and different positioning capabilities. In the follow-up work, we apply rich signal characteristics to indoor networking in typical demonstration scenarios, explore more flexible, lower cost, and more convenient networking methods, and provide technology and experience for the further market application of pseudolite accumulation.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare no conflict of interest.

Authors' Contributions

All authors contributed to the manuscript and discussed the results. All authors together developed the idea that led to this paper. H.Z and J.C conceived the experiments and analyzed the data. L.H. and Y.L. performed data processing and contributed to the manuscript. B.Y. and S.P. provided critical comments and contributed to the final revision of the paper. C.S. and X.L contributed to the expression and the design of programs.

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References

[1] S. Liu, L. Wang, and Z. Yao, "Research on layout method of ground-based pseudolite positioning system based on NSGA-II algorithm," *Application Research of Computers*, vol. 37, pp. 1839–1843, 2020.

[2] X. Xue and L. Wang, "Pseudolite base station selection method based on weighted level precision factor," *Geodesy and Geodynamics*, vol. 39, pp. 1070–1075, 2019.

[3] J. Meng, *Research on Pseudolite Positioning Technology and Network Configuration*, PLA Information Engineering University, 2007.

[4] L. Wang, *Pseudolite Enhanced Beidou System Performance Analysis and Networking Technology Research*, Wuhan University of Technology, 2014.

[5] X. He, *Research on Key Technologies of Pseudo-Satellite Navigation Based on Neighboring Space Network Nodes*, University of Electronic Science and Technology, 2014.

[6] L. Zeng, D. Li, Y. Qu, A. Ren, and Y. Feng, "Route planning algorithm for space-based pseudolite network deployment," *Journal of Beijing University of Aeronautics and Astronautics*, vol. 42, pp. 1388–1397, 2016.

[7] J. Jia, *Research and Implementation of Time Synchronization Technology for Multi-mode Pseudolites Self-organizing Network*, Xidian University, 2014.

[8] Z. Xiao, *Research and Implementation of TC-OFDM Indoor Positioning Signal Networking and Time Synchronization*, Beijing University of Posts and Telecommunications, 2018.

[9] K. Fujii, Y. Sakamoto, W. Wang, H. Arie, A. Schmitz, and S. Sugano, "Hyperbolic positioning with antenna arrays and multi-channel pseudolite for indoor localization," *Sensors*, vol. 15, no. 10, pp. 25157–25175, 2015.

[10] J. H. Lee, D. H. Yu, and S. J. Lee, "Software-based performance analysis of a pseudolite time synchronization method depending on the clock source," *Journal of Positioning, Navigation, and Timing*, vol. 3, no. 4, pp. 163–170, 2014.

[11] X. Gu, J. Li, G. Zhou, and S. Xie, "Improved clock parameters tracking and ranging method based on two-way timing stamps exchange mechanism," *IEEE Signal Processing Letters*, vol. 28, pp. 598–602, 2021.

[12] T. Wang, Z. Yao, and M. Lu, "Mesh topology based clock synchronization technique for pseudolite systems," *Navigation*, vol. 67, no. 3, pp. 619–632, 2020.

[13] C. Ma, J. Yang, J. Chen, and Y. Tang, "Time synchronization requirement of global navigation satellite system augmentation system based on pseudolite," *Measurement and Control*, vol. 52, no. 3-4, pp. 303–313, 2019.

[14] T. Wang, Z. Yao, S. Yun, and M. Lu, "A new network-based synchronization approach for pseudolite and improvements on robustness," in *Proceedings of the 29th International Technical Meeting of the Satellite Division of the Institute of Navigation (ION GNSS+2016)*, pp. 838–844, Portland, Oregon, 2016.

[15] X. Xue, H. Qin, and H. Lu, "High-precision time synchronization of kinematic navigation system using GNSS RTK differential carrier phase time transfer," *Measurement*, vol. 176, pp. 102241–109132, 2021.

[16] X. Gan, B. Yu, L. Huang et al., "Doppler differential positioning technology using the BDS/GPS indoor array pseudolite system," *Sensors*, vol. 19, no. 20, p. 4580, 2019.

[17] L. Huang, X. Gan, B. Yu et al., "An innovative fingerprint location algorithm for indoor positioning based on array pseudolite," *Sensors*, vol. 19, no. 20, p. 4420, 2019.

[18] X. Li, G. Huang, P. Zhang, and Q. Zhang, "Reliable indoor pseudolite positioning based on a robust estimation and partial ambiguity resolution method," *Sensors*, vol. 19, no. 17, p. 3692, 2019.

[19] Q. Liu, Z. Huang, Y. Kou, and J. Wang, "A low-ambiguity signal waveform for pseudolite positioning systems based on chirp," *Sensors*, vol. 18, no. 5, p. 1326, 2018.

[20] C. Sheng, X. Gan, B. Yu, and J. Zhang, "Precise point positioning algorithm for pseudolite combined with GNSS in a constrained observation environment," *Sensors*, vol. 20, no. 4, p. 1120, 2020.

[21] Q. Sultana, D. Sunehra, V. S. Srinivas, and A. D. Sarma, "Effects of pseudolite positioning on DOP in LAAS," *Positioning*, vol. 1, no. 1, pp. 18–26, 2010.

[22] D. Weng, X. Gan, W. Chen, S. Ji, and Y. Lu, "A new DGNSS positioning infrastructure for android smartphones," *Sensors*, vol. 20, no. 2, p. 487, 2020.

[23] H. Zhang, S. Pan, C. Sheng et al., "An indoor DFEC ranging method for homologous base station based on GPS L1 and BeiDou B1 signals," *Sensors*, vol. 20, no. 8, p. 2225, 2020.

[24] Y. Zhao, P. Zhang, J. Guo et al., "A new method of high-precision positioning for an indoor pseudolite without using the known point initialization," *Sensors*, vol. 18, no. 6, 2018.

[25] R. Zhu, Y. Wang, H. Cao et al., "RTK/pseudolite/LAHDE/IMU-PDR integrated pedestrian navigation system for urban and indoor environments," *Sensors*, vol. 20, no. 6, p. 1791, 2020.