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Research Article

Research on Wireless Positioning Technology Based on Digital FM Broadcasting

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With more and more new mobile devices (such as mobile phones, tablets, and wearable devices) entering people's daily life, along with the application and development of relevant technologies based on users' location information, location based service is becoming a basic service demand of people's life. This paper puts forward a research on location technology based on frequency modulation band digital audio broadcasting (FM China Digital Radio, FM-CDR). A new method of adding timestamp information to the FM-CDR frame structure is proposed, which verified that the change to the system does not affect the normal transmission and reception of broadcast content under the original standards and can accurately extract the recognition signal and timing information of BS. In the complex environment, the estimation algorithm of signal parameters such as received signal strength (RSS), time of arrival (TOA), and time difference of arrival (TDOA) of terrestrial radio broadcast signals is studied. In this paper, a new method based on multisource data fusion is proposed, which can meet the need of localization in various environments and overcome the deficiency of single localization method.

1. Introduction

Mobile location technology based on digital broadcasting network, in this article, mainly refers to the use of signals of digital terrestrial broadcasting radio base station (BS). Mobile station (MS) receives the wireless positioning signal to determine its own position or coordinates by inserting the high-precision timing information into the broadcast signal data frame. This paper has effectively expanded the research ideas of related technologies, combined digital broadcasting technology and positioning technology, and effectively realized the organic integration of different technologies under the background of three-network integration. This paper mainly discusses and studies the key technologies to realize the positioning function based on digital broadcasting signal, and on this basis, a wireless positioning algorithm suitable for digital broadcasting signals, as well as for the broadcast signal localization related technical scheme design, is proposed.

(1) Identification of radio digital broadcasting signals which are transmitted from different BS is an important difficulty in realizing the positioning system. Generally, in the digital broadcasting signal single-frequency network (SFN), signals of different BS are sent at the same time and at the same frequency with the same transmission content. Therefore, it is impossible to distinguish different BS from the perspective of receiving signal frequency and content. In addition, on the premise that the broadcast network signal system is not modified, the signal from different BS cannot be recognized spatially. The FM-CDR system does not provide the timing information, which makes it difficult to realize the positioning function. Therefore, the problem of obtaining the ranging information needs to be solved.

(2) Selection of positioning algorithm. The current mainstream positioning algorithm needs to obtain positioning parameters according to the received radio signal and the location of the commonly used parameters including the received signal strength (RSS), time of arrival (TOA), time difference of arrival (TDOA), and angle of arrival (AOA), each of which corresponds to the different application environment; the choice often determines the precision of system and the hardware overhead. In this paper, range-based positioning parameters are selected, including TOA,

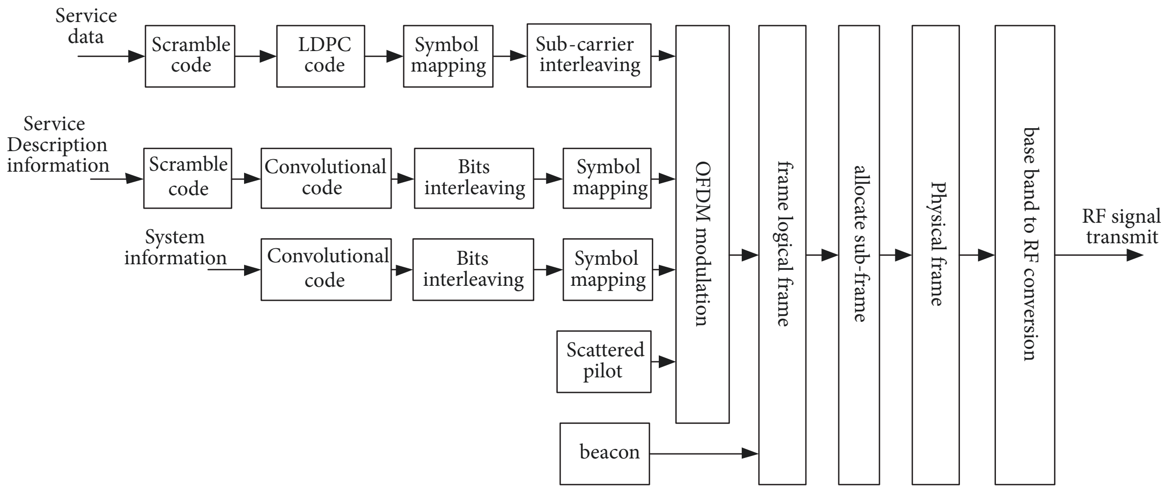

Figure 1: Physical layer logical channel coding and modulation system function box.

TDOA, and RSS methods. At present, various literature works provide a wide range of localization algorithms, such as least square (LS) algorithm, grid search localization algorithm based on feasible domain, and extended Kalman filtering positioning algorithm.

2. BS Identification Code and Timing Information

The FM-CDR is a technical standard with independent intellectual property rights developed in China. The standard of "frequency modulation frequency band digital audio broadcasting part 1: digital broadcasting channel frame structure, channel coding and modulation" was officially issued in August 2013:GY/T 268.1-2013 [1]; the standard of "FM frequency band digital audio broadcasting part 2: reuse" was officially released in November 2013: GY/T 268.2-2013 [2]; 6 interim technical requirements were issued on December 3, 2014, covering source coding technology (DRA+), encoder, multiplexer, actuator, transmitter, and test receiver. The working frequency of FM digital broadcasting is 87~108 MHz, which is consistent with the current analog stereo FM radio frequency band. Analog/digital signal co-broadcast and future transition to full frequency digital broadcasting can be realized, which is both present and future oriented.

The FM-CDR system realizes the broadcast of digital audio broadcasting and data service through digital encoding and modulation technology. Multichannel digital audio and data services can be transmitted simultaneously. The functions of the physical layer of the FM-CDR transmission system are shown in Figure 1. After the service data, service description information and system information from the upper layer are processed by channel coding (scramble code, Low Density Parity Check coding, convolutional code) and symbol mapping. Orthogonal Frequency Division Multiplexing (OFDM) modulation is carried out together with scattered pilot. The modulated signal is then added to a beacon composed of pseudo-random codes to form a logical frame, which is then allocated through subframes to form a physical layer signal frame, and finally the baseband signal is converted to the radio frequency signal transmission.

From the FM-CDR digital broadcasting standards, it is not difficult to find that the standard does not have the relevant information necessary to complete the positioning function: the BS identification information is not provided. Compared with the China Mobile Multimedia Broadcasting (CMMB) data frame structure of multimedia broadcasting technology, this standard removes the part of data frame header transmitter identification (TxID), which increases the difficulty of BS identification. Without adding timing information at the sending end, MS cannot extract positioning parameters such as the exact moment of data frame transmission and cannot realize positioning function.

The CDR timestamp format (112 bit) designed as discussed elsewhere [3] is shown in Figure 2.

Generation time of logical frame: 40 bits, representing the generation time of current logical frames. The multiplexer reads the Global Positioning System (GPS) time at startup and takes the integer seconds at startup as the time of generation of the first logical frame of the first super frame 0, and the number of milliseconds of this logical frame is 0. The multiplexer reads the GPS time every 16 seconds as the generation time of the current logical frame.

Base station addressing: 16 bit, used to address a transmitter in the single-frequency network. The addressable range is from 0x0000 to 0xffff, where 0x0000 represents all transmitters within the addressing network.

The two fields of maximum delay time and independent adjustment delay are not discussed in this paper.

Timestamp information is located in the multiplexed steam; it is sent before the service data, system information, and other information, just for security CDR system SFN networking needs; this guarantees work time unification of each actuator system, and it is not actually sent to the transmitter, so MS cannot receive the timestamp information.

The system information used by FM-CDR is composed of 48 bits, including encoding code rate, data modulation mode,

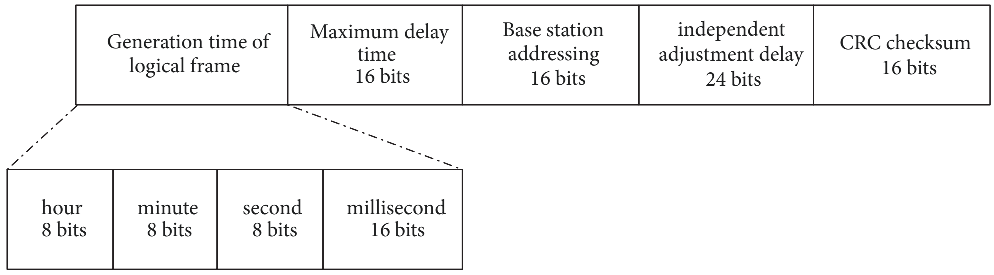

FIGURE 2: Format of timestamp information.

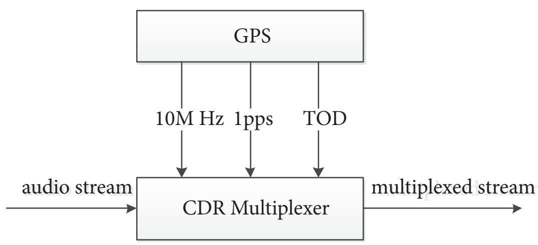

FIGURE 3: Adding time information to multiplexed stream.

current subframe position, spectral pattern index, and other information.

A logical subframe carries 108 system information symbols, which are modulated by QPSK. Each symbol represents 2 bits. Therefore, a subframe actually carries 216 bits of system information. Except for the 48 bits that have been taken, there are 168 that are available. The timestamp information can be added to achieve the positioning function timing requirements. In order to ensure the integrity of the existing broadcast signal system, the inserted information does not change the channel frame structure and does not affect the transmission and reception of the original broadcast signal. It is feasible to use the timestamp information shown in Figure 2 as the timing information needed to realize localization. This paper inserted the timestamp information (112 bit) into the system information of the first logical subframe of each logical frame, after the system occupied 48 bit information.

It should be noted that the time information TOD shown in Figure 3 is only the time when the logical frames are generated, and the TOD value is the same for each BS. From the perspective of positioning function, it is necessary to pay attention to the absolute moment when each BS sends out the frame signal. It is necessary to add the "logical frame generation time", "maximum delay time", and "independent adjustment delay time" in the time stamp message format to obtain the "t_{TOD}" of the absolute transmission time of radio frequency signal.

In addition, the "base station addressing" field in the timestamp information can be used to identify different BS to obtain the BS geographic location information, its antenna height information (the geographic location information in this paper is stored in MS), etc.

3. Wireless Positioning Algorithm and Acquisition of Ranging Parameters

3.1. Acquisition of FM-CDR Ranging Location Parameters

3.1.1. TOA Value. Follow these steps to get TOA value:

(1) MS uses the beacon to carry out subframe synchronization, and simultaneously records the time "t".

(2) Use OFDM demodulation to obtain system information.

(3) Carry out logical frame synchronization, find the subframe that carries the timestamp information, and obtain the "t_{TOD}" of the sending time of this subframe.

(4) Compare the synchronized subframes in step (1), and the number of subframes with timestamp information is "n" (n=0~4; logical frames are composed of 4 subframes).

(5) TOA value = t-t_{TOD} +n∗160 ms.

According to the base station addressing field in step (3) timestamp information, the geographical position coordinates of the BS are obtained.

3.1.2. TDOA Value. After obtaining the TOA parameters of multiple BSs, take the BSs corresponding to the minimum value of TOA as the BS 1, and then subtract the TOA value of the remaining BS from the TOA value of the BS 1 to get the multiple sets of TDOA parameters. In particular, in SFN, since each BS sends the same content at the same time, TDOA parameters can be obtained by the generalized cross-spline GCC [4] method. The core of this algorithm is to solve the TDOA of signal transmission between the two BSs by receiving two signals from two different BSs in SFN and calculating their mutual correlation function. In addition, RSS ranging parameters can be introduced to obtain the TDOA value when two or more sets of TDOA values cannot be obtained (at this point, the geographical location of the BS needs to be predicted).

3.1.3. RSS Method. According to the relationship between wireless signal intensity and spatial location, the "signal intensity-distance" model was constructed. With the increase of signal propagation distance, the signal intensity gradually becomes weaker, and the attenuation of signal intensity and distance form a certain mathematical relationship. In indoor environment, wireless signals obey reflection, scattering, and diffraction.

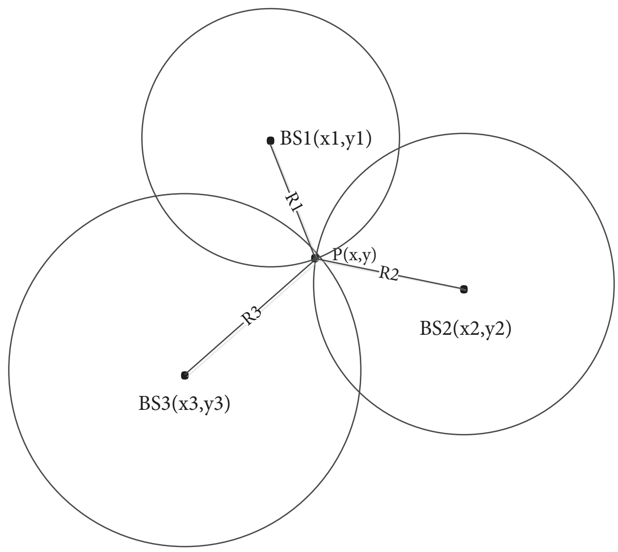

Figure 4: TOA ranging principle.

At present, Shadowing model [5] is widely adopted as the transmission model of indoor wireless signals based on RSS ranging algorithm as follows.

$$P(d) = P(d_0) + 10n\log_{10}\left(\frac{d}{d_0}\right) + \xi \quad (1)$$

In (1), d_0 is the reference distance, which is always 1 m, d is the actual distance, $P(d)$ and $P(d_0)$ are the path loss values when the distance is d and d_0 respectively, and ξ is the masking factor. A simplified Shadowing model is usually used as follows.

$$P(d) = P(d_0) + 10n\log_{10}\left(\frac{d}{d_0}\right) \quad (2)$$

In addition, the path loss is equal to the difference between the initial sending signal intensity and the receiving signal intensity; that is, $P(d) = P(0)\text{-}RSS(d)$ and $P(d_0) = P(0)$ - $RSS(d_0)$, where $P(0)$ is the initial sending signal intensity, and $RSS(d)$ and $RSS(d_0)$ are the receiving signal intensity values at distances of d and d_0. Normally, choose $d_0 = 1m$, $A = -RSS(d_0)$ to obtain the actual RSS ranging formula.

$$RSS(d) = -\left(10n\log_{10}d + A\right) \quad (3)$$

In (3), n is the signal transmission constant related to the signal transmission environment and A is the absolute value of the average RSS value measured at distance BS 1m.

The FM-CDR RF receiving chip can generally provide RSS values directly, so RSS can be used to measure distances without additional hardware, so the cost of positioning by using this technology is low. However, due to the complex indoor environment, even in the same distance with BS, many factors have different degrees of RSS loss on the signal, resulting in a large distance error measured by RSS value. It can be used as an alternative in some cases where sufficient BSs' signal cannot be obtained.

3.2. Wireless Positioning Algorithm. This paper mainly studies the geometric localization algorithm based on ranging [6].

By measuring the distance between the known reference point and the unknown target, the geometric localization method calculates the position information of the unknown target. This method is the most widely used positioning algorithm, distance measuring methods including those based on TOA, TDOA, and RSS [7–14].

(1) TOA Method. The principle is to measure the time when the signal from three or more BSs reaches the MS; according to the known radio transmission speed, the distance between the BSs and the MS can be uniquely determined. See Figure 4.

The distances between MS and BS1, BS2, and BS3 were measured, respectively, R1, R2, and R3. Then, MS is on the circle with BS coordinates as the center and the distance between MS and BS as the radius. Therefore, it forms three circles with three BSs, and the MS is at the intersection point of three circles; the equations are shown below:

$$\sqrt{\left(x_i - x_0\right)^2 + \left(y_i - y_0\right)^2} = d_i \quad i = 1, 2, 3 \quad (4)$$

where (x_i, y_i) are known BS coordinates, (x_0, y_0) are terminal coordinates, and d_i is the distance between MS and BSi.

However, this method has a high requirement for clock synchronization between BS and MS (1us clock synchronization error can lead to a distance error of 300 meters), so the cost of MS is greatly increased, and sometimes it cannot even achieve time synchronization.

In this paper, the LS (least square) method is used to solve nonlinear equations to obtain MS coordinates.

The LS solution is as follows.

$$\hat{x} = \left(H^T H\right)^{-1} H^T b \quad (5)$$

In (5)

$$H = \begin{bmatrix} x_2 - x_1 & y_2 - y_1 \\ x_3 - x_1 & y_3 - y_1 \\ \vdots & \vdots \\ x_n - x_1 & y_n - y_1 \end{bmatrix},$$

$$\hat{x} = \begin{bmatrix} x_0 \\ y_0 \end{bmatrix} \quad (6)$$

$$b = \frac{1}{2}\begin{bmatrix} x_2^2 + y_2^2 + d_2^2 - \left(x_1^2 + y_1^2 + d_1^2\right) \\ x_3^2 + y_3^2 + d_3^2 - \left(x_1^2 + y_1^2 + d_1^2\right) \\ \vdots \\ x_n^2 + y_n^2 + d_n^2 - \left(x_1^2 + y_1^2 + d_1^2\right) \end{bmatrix}.$$

(2) RSS Method. RSS positioning algorithm is the same as the TOA method. The only difference is that the distance d between BSs and MS is obtained by different methods.

(3) TDOA Method. Measure the time difference between two or more BSs reaching the MS, and use this time difference to

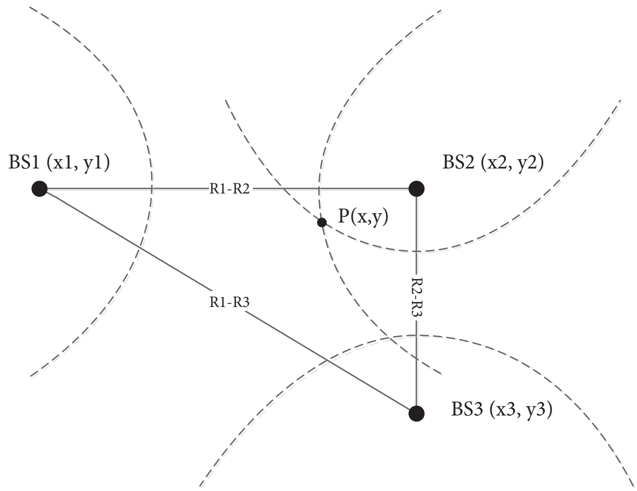

FIGURE 5: TDOA ranging principle.

calculate the MS position. Compared with the TOA method, the MS is not required to synchronize clock strictly with the BS. Most land-based navigation systems use this method. The principle is shown in Figure 5.

Similar to TOA methods, in the case of a BS*i* site marked as *(xi, yi)*, MS site marked as (x_0, y_0), MS and BS1 distance with BS2 difference for Δd_2, MS and BS1 and BS3 distance difference for Δd_3, the MS is at the intersection of two sets of hyperbola. It can be obtained by solving (7). In the case of multiple sets of solutions, solutions that do not match the actual position are easily ruled out.

$$\begin{aligned}\sqrt{(x_2-x_0)^2+(y_2-y)^2}-\sqrt{(x_1-x_0)^2+(y_1-y_0)^2} &= \Delta d_2\\ \sqrt{(x_3-x_0)^2+(y_3-y)^2}-\sqrt{(x_1-x_0)^2+(y_1-y_0)^2} &= \Delta d_3\end{aligned} \tag{7}$$

When the BS number is greater than 3, the LS method is used to solve the nonlinear equations.

$$\hat{x} = \left(H^T H\right)^{-1} H^T \left(d_1 a + b\right) \tag{8}$$

In (8)

$$H = \begin{bmatrix} x_2-x_1 & y_2-y_1\\ x_3-x_1 & y_3-y_1\\ \vdots & \vdots\\ x_n-x_1 & y_n-y_1\end{bmatrix},$$

$$x = \begin{bmatrix} x_0\\ y_0\end{bmatrix}$$

$$a = \begin{bmatrix} -\Delta d_2\\ -\Delta d_3\\ \vdots\\ -\Delta d_n\end{bmatrix}$$

$$b = -\frac{1}{2}\begin{bmatrix} \Delta d_2^2 - x_2^2 - y_2^2 + x_1^2 + y_1^2\\ \Delta d_3^2 - x_3^2 - y_3^2 + x_1^2 + y_1^2\\ \vdots\\ \Delta d_n^2 - x_n^2 - y_n^2 + x_1^2 + y_1^2\end{bmatrix}. \tag{9}$$

After the estimated value is obtained by using LS, it can be used as the initial value of Taylor series least square method for iterative calculation, which can further improve the positioning accuracy. The local LS solution of TDOA error is solved through multiple iterative calculations to gradually improve the position of MS estimation [15].

The process of collaborative calculation of TDOA coordinates by LS and Taylor method is shown in Figure 6.

Process of the algorithm: for the TDOA nonlinear equations of (7), first, its MS initial position $(x_{0,}y_0)$ is expanded to Taylor series. If the terms of the second order are discarded, (7) can be converted to the following.

$$h_t = G_t\delta + \varepsilon \tag{10}$$

In (10)

$$\delta = \begin{bmatrix} \Delta x\\ \Delta y\end{bmatrix},$$

$$h_t = \begin{bmatrix} \Delta d_2 - (d_2 - d_1)\\ \Delta d_3 - (d_3 - d_1)\\ \vdots\\ \Delta d_n - (d_n - d_1)\end{bmatrix},$$

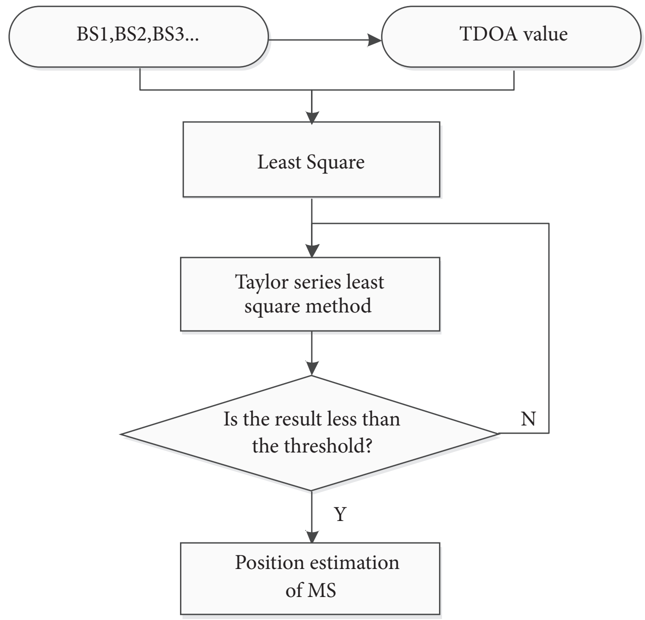

Figure 6: Collaborative calculation of TDOA coordinates by LS and Taylor method.

$$G_t = \begin{bmatrix} \left[\frac{(x_1 - x_0)}{R_1}\right] - \left[\frac{(x_2 - x_0)}{R_2}\right] & \left[\frac{(y_1 - y_0)}{R_1}\right] - \left[\frac{(y_2 - x_0)}{R_2}\right] \\ \left[\frac{(x_1 - x_0)}{R_1}\right] - \left[\frac{(x_3 - x_0)}{R_3}\right] & \left[\frac{(y_1 - y_0)}{R_1}\right] - \left[\frac{(y_3 - x_0)}{R_3}\right] \\ \vdots & \vdots \\ \left[\frac{(x_1 - x_0)}{R_1}\right] - \left[\frac{(x_n - x_0)}{R_n}\right] & \left[\frac{(y_1 - y_0)}{R_1}\right] - \left[\frac{(y_n - x_0)}{R_n}\right] \end{bmatrix}. \tag{11}$$

The weighted least squares solution is as follows.

$$\delta = \begin{bmatrix} \Delta x \\ \Delta y \end{bmatrix} = \left(G_t^T Q G_t\right)^{-1} G_t^T Q^{-1} h \tag{12}$$

The Q stands for TDOA measurements covariance matrix, and the initial iteration, to $x = x_0$, $y = y_0$, in the next iteration, makes $x^{(1)} = x_0 + \Delta x$, $y^{(1)} = y_0 + \Delta y$.

The process is repeated until the preset threshold of "top" is met, so that

$$|\Delta x| + |\Delta y| < \varepsilon. \tag{13}$$

Through the K iteration, get the location of the (x^K, y^K) to estimate the position of MS $(\hat{x}, \hat{y})$.

Taylor series least square method is simple and easy to implement.

(4) TOA, TDOA, and RSS Weighted Joint Positioning. Each method has its advantages and disadvantages in different applications. Single positioning algorithm can no longer meet the needs of high-precision positioning. Multi-algorithm fusion positioning and multi-base station collaborative positioning are the main trends of indoor positioning at present. In this paper, an optimal linear weighting method is proposed to further process the location obtained by combining different methods, so as to meet the requirements of positioning in various environments and further reduce the positioning error.

Set:

Calculated based on TOA location coordinates for (x_1, y_1), variance is σ_1^2.

Calculated based on TDOA position location coordinates for (x_2, y_2), variance is σ_2^2.

Calculated based on RSS positioning coordinates for (x_3, y_3), variance is σ_3^2.

Then the output of the final location estimation is as follows.

$$\begin{aligned} \hat{x} &= \frac{\sigma_2^2 + \sigma_3^2}{\sigma^2} x_1 + \frac{\sigma_1^2 + \sigma_3^2}{\sigma^2} x_2 + \frac{\sigma_1^2 + \sigma_2^2}{\sigma^2} x_3 \\ \hat{y} &= \frac{\sigma_2^2 + \sigma_3^2}{\sigma^2} y_1 + \frac{\sigma_1^2 + \sigma_3^2}{\sigma^2} y_2 + \frac{\sigma_1^2 + \sigma_2^2}{\sigma^2} y_3 \end{aligned} \tag{14}$$

4. Experimental Simulation Platform

This section compares the performance of TOA, TDOA, and RSS positioning algorithms under AWGN channel and non-line-of-sight (NLOS) conditions through MATLAB simulation. The average root error and the cumulative error distribution function (CDF) were used as the performance indexes.

The expression of root mean square error (RMSE) is as follows.

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}\left[(\hat{x} - x)^2 + (\hat{y} - y)^2\right]}{n}} \tag{15}$$

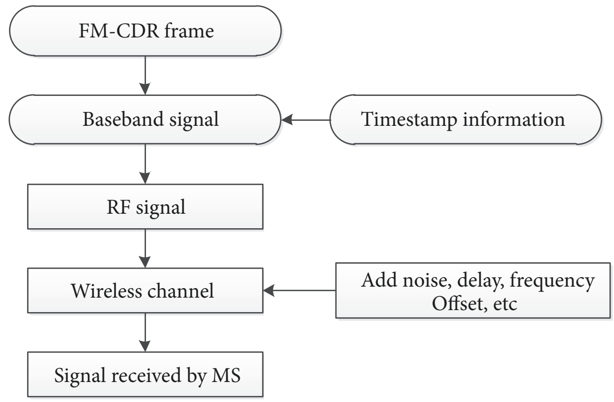

Figure 7: BS side simulation process.

In (15), $(\hat{x}, \hat{y})$ is calculated by the localization algorithm of MS position estimate. (x, y) is the true position of MS (preset in the simulation experiment).

This paper adopts the positioning network with symmetrical structure. It is assumed that the BS of FM-CDR single-frequency network is arranged according to cellular network. In the experiment, seven BSs were set. Establish a two-dimensional plane coordinate system. The 7 BS coordinates are set to $(0, 0)$, $(\sqrt{3}R, 0)$, $(\sqrt{3}R/2, 3R/2)$, $(-\sqrt{3}R/2, 3R/2)$, $(-\sqrt{3}R, 0)$, $(-\sqrt{3}R/2, -3R/2)$, and $(\sqrt{3}R/2, -3R/2)$. R is 5 km.

Preset FM-CDR mode: transmission mode 1, spectrum mode 9, system information, and service data all adopt symbol mapping of QPSK nonhierarchical modulation mode and carrier frequency of 90 MHz. The simulation times are all 1000.

At BS Side. According to [1] to generate standard service data, service description data, and system information data, insert timestamp information into system information specified location and then use OFDM modulation, according to transfer mode 1 after logical frame allocation, baseband signal generation, RF signal, add noise, delay, etc. The simulation process of BS side is shown in Figure 7.

At MS Side. The MS positioning process is mainly divided into three stages: positioning establishment and preparation, positioning calculation, and positioning update.

In the stage of positioning establishment and preparation, first load the carrier frequency of the regional BS signal, and then lower the frequency to the baseband signal. After sampling, the transmission mode of BS signal is determined according to CP length. Subframe synchronization using beacon: According to the determined transmission mode, the scattered pilot in the subcarrier matrix is obtained, and the channel estimation and equalization are carried out. The subcarriers (continuous pilot) carrying the system information are obtained. After the symbol mapping, bits interleaving, and convolution decoding of these subcarrier data, the system information such as spectrum mode, subframe position, and timestamp information inserted therein are obtained.

In the location calculation stage, first, obtain the location parameters TOA, TDOA, RSS, etc.; identify the existence of NLOS, restrain NLOS, and calculate the MS position.

In the positioning update stage, determine whether it is consistent with the actual situation; if the gap with the expected position is too large, the current estimation value will be omitted and then reestimated. The MS end localization simulation process is shown in Figure 8.

5. Simulation Results and Analysis

As can be seen from Figure 9, when 4 BSs are set, the performance of TDOA is obviously better than that of TOA under the same transmission conditions. Since the TOA algorithm needs the accurate synchronization between BS and MS clock, it brings a certain clock error for the positioning algorithm. The TDOA method has better performance because MS does not need to keep clock synchronization with BS.

As can be seen from Figure 10, when 4 BSs are set, under the same SNR and NLOS conditions, all three positioning errors increase to a certain extent as the system measurement error increases. From the positioning effect, the TDOA algorithm is closer to the Cramer-Rao Lower Bound (CRLB), and the positioning performance is better than the TOA algorithm. The TDOA algorithm of LS & Taylor's collaborative localization has a good ability to suppress the measurement error.

It can be seen from Figure 11 that under the condition of NLOS, TDOA positioning accuracy is better than TOA algorithm and TOA algorithm is better than RSS algorithm. The probability of TDOA making 17-meter error is 67% and 34-meter error is 95%. The error of the TOA algorithm is 41 meters with 95% probability. In the indoor environment, the error caused by NLOS is very obvious relative to the condition of LOS, and the positioning accuracy needs to be further improved.

It can be seen from Figure 12 that under the condition of NLOS, the precision of TDOA+TOA algorithm is optimal. The accuracy of TDOA+TOA+RSS combined algorithm is second, while the accuracy of TDOA+RSS is close to that

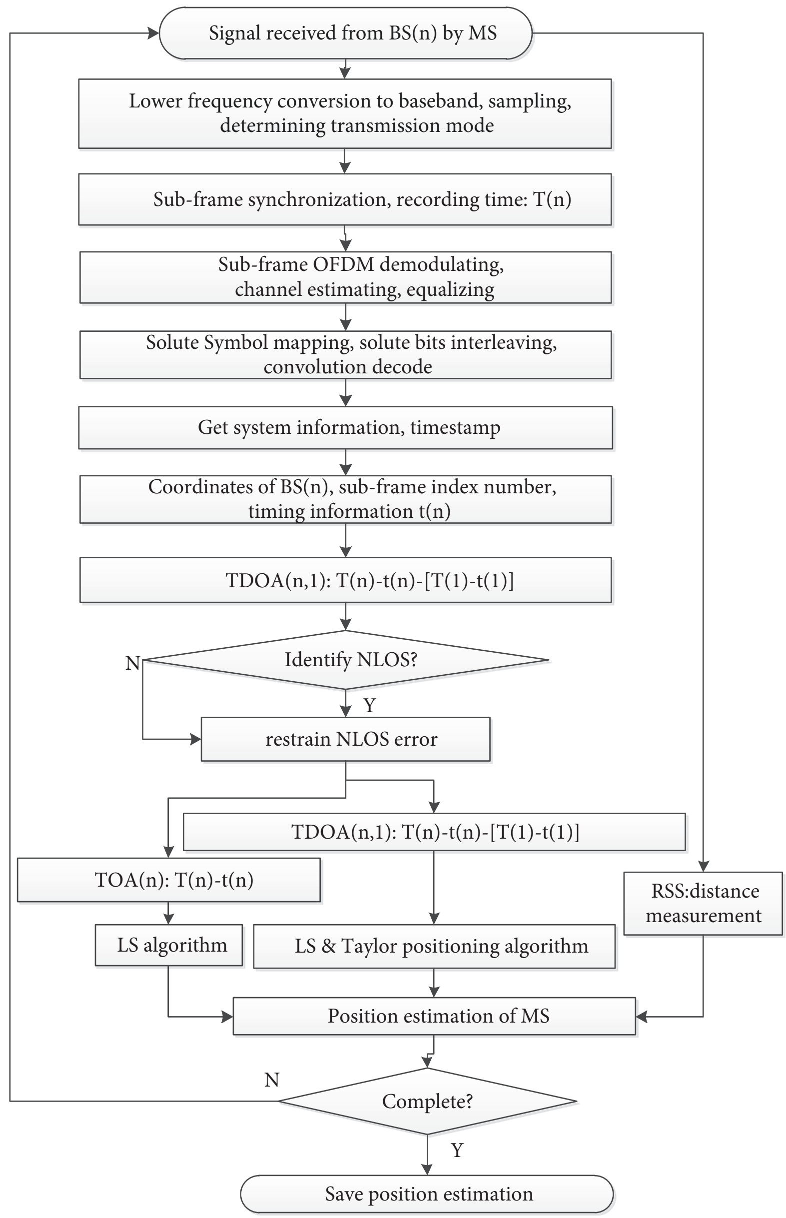

Figure 8: MS side simulation process.

of TOA+RSS algorithm. The probability of TDOA+TOA making 8-meter error is 67%, and the probability of 15-meter error is 95%, while TDOA+TOA+RSS algorithm has a 95% probability of 20-meter error.

It can be concluded that TDOA+TOA joint localization method is the best when MS can obtain enough BS signals; RSS positioning algorithm has the worst accuracy, because it participates in weight calculation with other algorithms. Therefore, the RSS positioning algorithm can only be used as an alternative when sufficient BS signals cannot be obtained. In general, using multisource data for joint localization calculation can effectively reduce the error when using a single algorithm. When MS can receive more BS signals, the positioning accuracy will be further improved.

6. Conclusions

In this paper, aiming at the deficiency of the signal of the FM-CDR digital broadcasting standard in positioning, on the basis of studying the existing standards, the channel frame is innovatively added with the timing information needed to identify the base station identification code and locate complete timing information design. According to the results of simulation experiments, this change of the system does not affect the normal transmission and reception of broadcast content under the original standard and can obtain the BS identification code and positioning timing information accurately.

Researching under complex indoor environment, on the grounds of RSS, TOA, and TDOA signal parameter

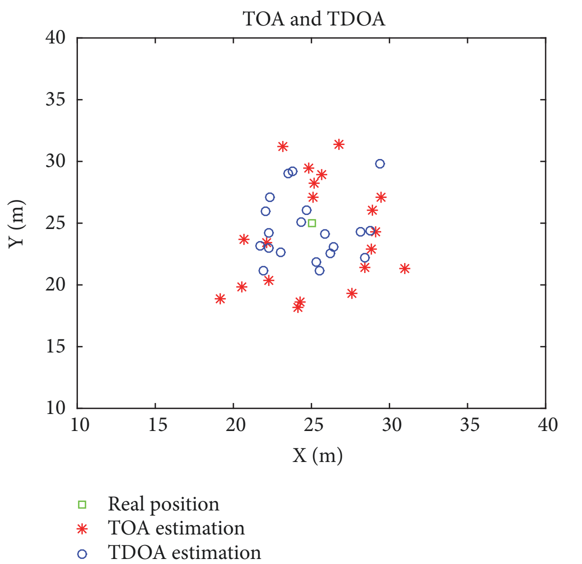

Figure 9: Comparison between TOA and TDOA positioning algorithm and the real position.

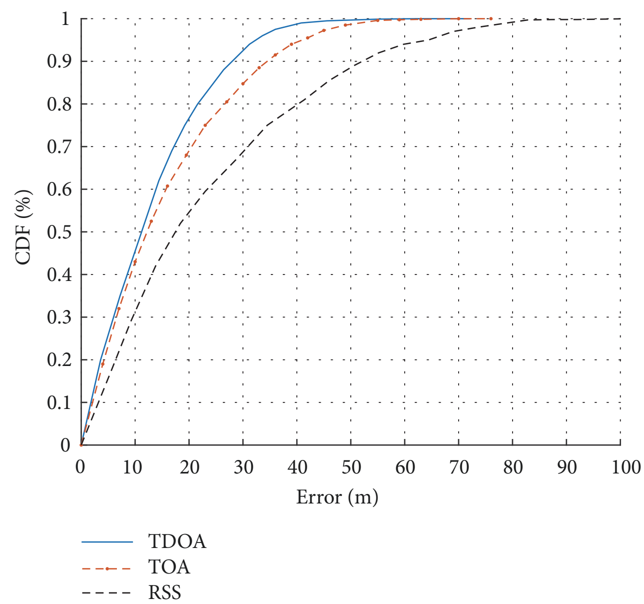

Figure 11: TOA, TDOA, and RSS range-finding in the NLOS condition CDF.

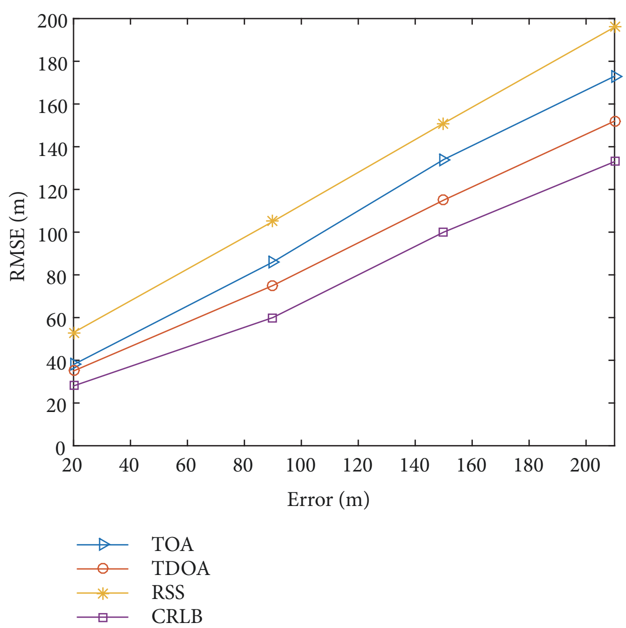

Figure 10: TOA, TDOA, and RSS range-finding algorithms under NLOS conditions RMSE.

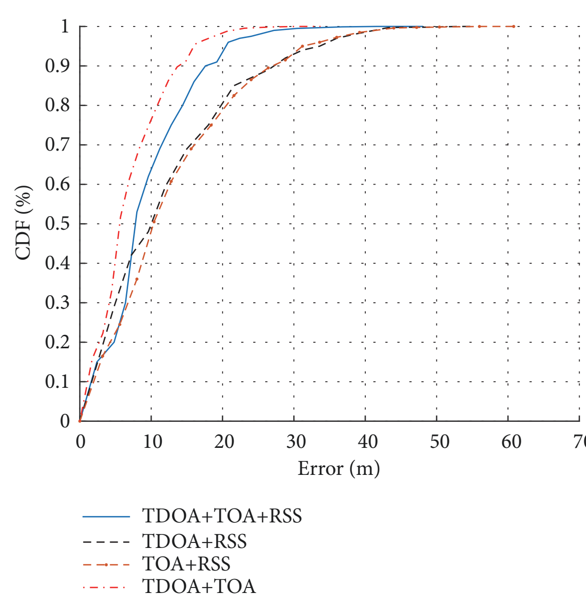

Figure 12: CDF with different joint localization algorithms under NLOS condition.

estimation algorithm, this paper proposed a fusion of multi-source data weighting positioning calculation method. It can better overcome the lack of a single positioning method and at the same time adapt to more scenes.

Data Availability

The data used to support the findings of this study are available from corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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