Research on High Precision Location Algorithm of NB Terminal Based on 5G/NB-IoT Cluster Node Information Fusion

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Abstract. With the development of the Internet of Things, a large number of connection requirements for sensing and control are generated. However, in wireless positioning, Narrowband Internet of Things (NB-IoT) has poor positioning accuracy which takes the cell-ID positioning method. The further integration of 5G and NB-IoT networks is expected to effectively improve the positioning accuracy of NB-IoT networks. Therefore, the high-precision positioning algorithm for researching converged networks has broad application prospects and academic significance. In order to improve the positioning accuracy of NB-IoT, based on the 5G and NB-IoT heterogeneous positioning framework, we propose to introduce a number of cluster nodes, which have the function of communicating with 5G and NB-IoT networks simultaneously. The signal bandwidth in NB-IoT network is narrow and clock synchronization is difficult to accomplish, so only DOA (Direction of Arrival) and RSSI principles can be considered. In this paper, we firstly use 5G to perform high-precision positioning of cluster nodes according to the principles of TDOA (Time Difference of Arrival). Based on the solution space $(x \pm \varepsilon_x, y \pm \varepsilon_y)$, the NB-IoT terminal is located by the cluster nodes according to the DOA and RSSI fusion method. This method helps reduce the matching time and improve the accuracy of single DOA/RSSI positioning method. Meanwhile, in the case of allowing cluster node errors, higher precision NB-IoT network positioning results can be obtained. Compared to a single NB-IoT network positioning, the final positioning accuracy of NB-IoT terminal can be improved by 80–90%.

Keywords: DOA · RSSI · Fusion positioning

1 Introduction

With the development of the Internet of Things, a large number of connection requirements for sensing and control are generated. This type of demand has low connection rate requirements, but is very sensitive to power consumption and cost, and is widely distributed and large in number. In wireless positioning, Narrowband Internet of Things (NB-IoT) has poor positioning accuracy, and cellular network has relatively high positioning accuracy with the help of TDOA, DOA information and so on. However, the

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current 3G/4G network cannot carry a huge number of IoT connections. The fifth generation communication system (5G) is expected to meet the needs of IoT connectivity, and the further integration of 5G and NB-IoT networks is expected to effectively improve the positioning accuracy of NB-IoT networks. Therefore, the high-precision positioning algorithm for researching converged networks has broad application prospects and academic significance.

As a sub-network of LTE, NB-IoT only supports the cell-ID positioning method [1]. The positioning accuracy of this method depends on the size of the cell, and generally exceeds 300 m. The 5G has more precise clock synchronization, ultra-wide bandwidth, and multi-antenna design. It supports TOA, TDOA, DOA and other positioning principles [2], and the positioning accuracy can reach the sub-meter level. However, 5G and NB-IoT belong to different networks. The 5G positioning information cannot be directly applied to the positioning of the NB-IoT terminal.

In order to improve the positioning accuracy of NB-IoT while preserving the low power consumption and low-cost characteristics of NB-IoT, based on the 5G and NB-IoT heterogeneous positioning framework, we propose to introduce a number of cluster nodes, which have the function of communicating with 5G and NB-IoT networks at the same time. The signal bandwidth in NB-IoT network [1] is narrow and clock synchronization is difficult to accomplish, resulting in the poor performance of TDOA algorithm then DOA and RSSI principles can be considered. The multi-antenna design of 5G in cluster nodes will be beneficial to DOA estimation. In traditional method, terminal in NB-IoT network is obtained by Cell-ID positioning method without heterogeneous positioning framework and fusion algorithm. It is believed that more positioning information can obtain more accurate positioning results. Therefore, based on the actual situation of the NB-IoT network and the new feature of the converged network, DOA and RSSI fusion algorithm is used on NB-IoT side to improve single-sided positioning performance and TDOA algorithm is used to obtain the position of cluster nodes. On the other hand, the process of solving the positioning result is a problem of solving multiple linear equations. Step-by-step positioning may result in a local optimal solution. The solution of the cluster node after the first TDOA algorithm has an error, which will affect the positioning result of the second step. In this paper, within the error range of the solution obtained in the first step, the global optimal solution is searched to obtain a more accurate positioning result. From the results, the positioning precision of this method is increased by 90% in the X direction.

The first section of this paper mainly introduces the problems of NB-IoT terminal positioning, main methods and defects, and the improved methods. In Sect. 2 the TDOA positioning model and CHAN algorithm are introduced. In Sect. 3 DOA and RSSI fusion algorithm is introduced and is compared with the single RSSI positioning method. In Sect. 4 the fusion algorithm on both sides with the DOA and RSSI fusion algorithm are compared and analyzed performance.

2 Traditional TDOA-Based Positioning on 5G Side

In this section, TDOA positioning model [3] and a general solution algorithm named CHAN [4] will be illustrated.

2.1 TDOA Positioning Model

The TDOA positioning model estimates the position of the terminal mainly by measuring the transmission time difference of the signal transmitted from the terminal to the positioning reference base station. The distance difference obtained by the transmission time difference is satisfied by a hyperbolic model which focuses on two positioning reference base stations. To get the estimated position of the terminal, it is theoretically only necessary to measure the difference in arrival time between the two groups. The intersection of the two sets of hyperbolic curves obtained is the position of the terminal we are solving. However, in practical applications, the two sets of parameters tend to be poor, so in this experiment four base stations are selected to ensure better positioning performance.

On a 2D plane, there are M base station where M is greater than or equal to 4. The base station coordinates are (x_i, y_i), where i = 1, 2, ⋯, M. Supposing that the terminal coordinates to be estimated are (x, y), use the first base station as a reference base station and R_i represents the distance from terminal to base station i. $R_{i,1}$ represents the difference between the distance from terminal to base station i and the distance from terminal to base station 1.

$$R_{i,1} = c\tau_{i,1} = R_i - R_1 \quad i = 2, \ldots M \tag{1}$$

where $R_i = \sqrt{(x_i - x)^2 + (y_i - y)^2}$, i = 1, 2, ⋯ , M, c is the propagation speed of radio waves in vacuum which equals to 3 * 10^8 m/s. $\tau_{i,1}$ is the difference between the time from terminal to base station i and the time from terminal to base station 1. The TDOA positioning model can be described as following Fig. 1.

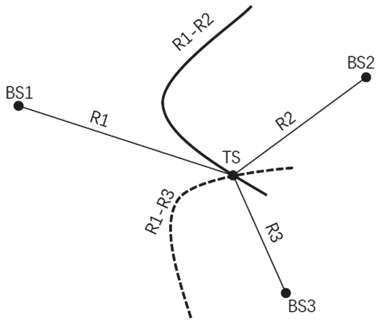

Fig. 1. TDOA positioning model

After applying linearization transform to formula (1), formula (2) is derived as follows:

$$\left(R_{i,1} + R_1\right)^2 = R_{i,1}^2 + 2R_{i,1}R_1 + R_1^2 = x_i^2 + y_i^2 - 2x_i x - 2y_i y + x^2 + y^2 \tag{2}$$

Let $K_i = x_i^2 + y_i^2$, $x_{i,1} = x_i - x_1$, $y_{i,1} = y_i - y_1$, then we get:

$$x_i x + y_i y + R_{i,1}R_1 = \frac{1}{2}\left(K_i - K_1 - R_{i,1}^2\right) \tag{3}$$

In formula (3) x and y are unknown and remain to be solved. Thus it can be thought as a set of linear formulas. The solution of the formulas is the location of the terminal to be estimated.

2.2 CHAN Algorithm

The CHAN algorithm is one of the classic algorithms based on TDOA measurement parameters.

Starting from formula (3), we can change it into linear formula (4)

$$G_a z_a = h \tag{4}$$

where $G_a = -\begin{pmatrix} x_{2,1} & y_{2,1} & R_{2,1} \\ x_{3,1} & y_{3,1} & R_{3,1} \\ x_{4,1} & y_{4,1} & R_{4,1} \end{pmatrix}$, $z_a = (x, y, R_1)^T$, h $= \frac{1}{2}\begin{pmatrix} R_{2,1}^2 - K_2 + K_1 \\ R_{3,1}^2 - K_2 + K_1 \\ R_{4,1}^2 - K_2 + K_1 \end{pmatrix}$. We define Z_a^0 as the value in the case of zero noise. Then the error vector can be described as:

$$e = h - G_a Z_a^0 \tag{5}$$

Supposing that e is statistically approximate to a Gaussian distribution and its covariance matrix exists, then we can get:

$$\psi = E\left(ee^T\right) = c^2 BQB \tag{6}$$

where B $=$ diag$\left\{R_2^0, R_3^0, R_4^0\right\}$, Q is the covariance matrix of noise vector which obeys Gaussian distribution.

Suppose the elements in z_a are independent of each other. After weighing the error of data in z_a, the problem becomes a weighted least squares problem. The formula to be solved becomes formula (7):

$$\left(G_a^T \psi G_a\right) z_a = G_a^T \psi h \tag{7}$$

The least squares estimate of z is

$$z_a = \left(G_a^T \psi^{-1} G_a\right)^{-1} G_a^T \psi^{-1} h \tag{8}$$

When the distance from terminal to base station is quite long, ψ can be substitute by Q. An approximation of z_a can be obtained as formula (9):

$$z_a \approx \tilde{z}_a = \left(G_a^T Q^{-1} G_a\right)^{-1} G_a^T Q^{-1} h \tag{9}$$

From the $\tilde{z}_a$ calculated by formula (9), the B matrix is recalculated. According to formula (6) ψ is calculated which is unknown before. Now formula (8) is available and the first estimate of z_a is obtained.

Use the first estimate of z_a to construct a set of error formula to obtain the second estimate of z_a as formula (10):

$$\begin{cases} z_{a,1} = x^0 + e_1 \\ z_{a,2} = y^0 + e_2 \\ z_{a,3} = R^0 + e_3 \end{cases} \tag{10}$$

where $z_{a,i}$ is one component of z_a and e_i is the estimate error of z_a. Then the second estimate of z_a is obtained by formula (11):

$$z_{a1} = \left(G_{a1}^T \psi_1^{-1} G_{a1}\right)^{-1} G_{a1}^T \psi_1^{-1} h_1 \tag{11}$$

Where $z_{a1} = \begin{pmatrix} (x - x_1)^2 \\ (y - y_1)^2 \end{pmatrix}$, $G_{a1} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \\ 1 & 1 \end{pmatrix}$, $h_1 = \begin{pmatrix} \left(z_{a,1} - x_1\right)^2 \\ \left(z_{a,2} - y_1\right)^2 \\ \left(z_{a,3}\right)^2 \end{pmatrix}$, $\psi_1 = 4B_1 cov(z_a) B_1$, $B_1 = diag\left\{x^0 - x_1, y^0 - y_1, R_1^0\right\}$, $cov(z_a) = \left(G_a^{0T} \psi^{-1} G_a^0\right)^{-1}$.

Finally, the estimate solution of terminal's position is as formula (12):

$$(x, y)^T = \pm\sqrt{z_{a1}} + (x_1, y_1)^T \tag{12}$$

Traditional TDOA-based positioning requires signals with high precision clock resolution and complex clock synchronization and has poor performance at NLOS scene [5–7], which is its drawbacks and limitations. NB-IoT network doesn't support such characteristic without high precision clock or synchronization. That's why DOA and RSSI fusion algorithm [8–10] is used in NB-IoT network rather than TDOA.

3 Novel DOA and RSSI Fusion Method on NB-IoT Side

3.1 DOA Positioning Model

Assuming that there are D signal sources in the far field of the antenna array, all the signal received by the antenna array approximately are plane wave. If the antenna array consists of M omnidirectional antennas and the first element set as the reference element, the ith signal received by the reference element is as follows:

$$s_i(t) = z_i(t) e^{j\omega_0 t}, \mathrm{i} = 0, 1, \mathrm{L}, \mathrm{D} - 1 \tag{13}$$

where $z_i(t)$ is the complex encircled modulating of the i-th signal, which including the information of signal. $e^{j\omega_0 t}$ is the carrier wave of space signal. Due to the narrowband hypothesis condition, the signal with propagation delay τ can be represented as formula (14):

$$s_i(t - \tau) = z_i(t - \tau) e^{j\omega_0 (t - \tau)} \approx s_i(t) e^{-j\omega_0 \tau}, \mathrm{i} = 0, 1, \mathrm{L}, \mathrm{D} - 1 \tag{14}$$

Ideally the signal received by the m-th element can be represented as formula (15):

$$x_m(\mathrm{t}) = \sum\nolimits_{i=0}^{D-1} s_i(t - \tau_{mi}) + n_m(\mathrm{t}) \tag{15}$$

where τ_{mi} is the time delay of the i-th array element relative to the reference array element when it reaches the m-th array element, n_m(t) is additive noise of the m-th element. Generally, signal received by the whole antenna array is represented as formula (16):

$$\mathrm{X(t)} = \sum\nolimits_{i=0}^{D-1} s_i(t)a_i + \mathrm{N(t)} = \mathrm{AS(t)} + \mathrm{N(t)} \tag{16}$$

where $a_i = \left[e^{-j\omega_0\tau_{1i}}, e^{-j\omega_0\tau_{2i}}, L, e^{-j\omega_0\tau_{Mi}}\right]^T$ is the direction vector of the i-th signal, $\mathrm{A} = \left[a_0, a_1, L, a_{D-1}\right]$ is the array manifold, S(t) is the signal matrix and N(t) is the additive noise matrix.

3.2 MUSIC Algorithm

MUSIC algorithm is also known as Multiple Signal Classification algorithm [11]. It can be described as the following steps:

1. Collect signal samples as X(n), n = 0, 1, L, K−1, and estimate covariance function as formula (17):

$$\hat{R}_X = \frac{1}{P}\sum\nolimits_{i=0}^{P-1} XX^H \tag{17}$$

   where P is the number of sampling points.
2. Apply eigenvalue decomposition on $\hat{R}_X$:

$$\hat{R}_X\mathrm{V} = \Lambda\mathrm{V} \tag{18}$$

   where $\Lambda = \mathrm{diag}(\lambda_0, \lambda_1, \mathrm{L}, \lambda_{M-1})$ is eigenvalue diagonal array and is arranged from largest to smallest, V is the corresponding feature vector.
3. According to the number of minimum eigenvalue K we can calculate the number of signal $\hat{D}$ by $\hat{D} = \mathrm{M} - \mathrm{K}$. Construct the noise subspace as V_N.
4. Define the MUSIC spatial spectrum as:

$$P_{MUSIC}(\theta) = \frac{a^H(\theta)a(\theta)}{a^H(\theta)V_N V_N^H a(\theta)} \tag{19}$$

   and then search the spectrum to find $\hat{D}$ peaks, which is the estimate value of DOA.

3.3 RSSI Positioning Model

RSSI is also known as Received Signal Strength Indication [12]. The basic idea is to discretize the area to be located and collect the signal strength information of each discrete point to create a fingerprint information database, which called location fingerprint library. Whenever need to estimate a terminal's position, we find the point in the library that best matches the point to be located. Generally, basic location fingerprint positioning system consists of two parts: offline fingerprint generation and online fingerprint matching. The model can be described as Fig. 2.

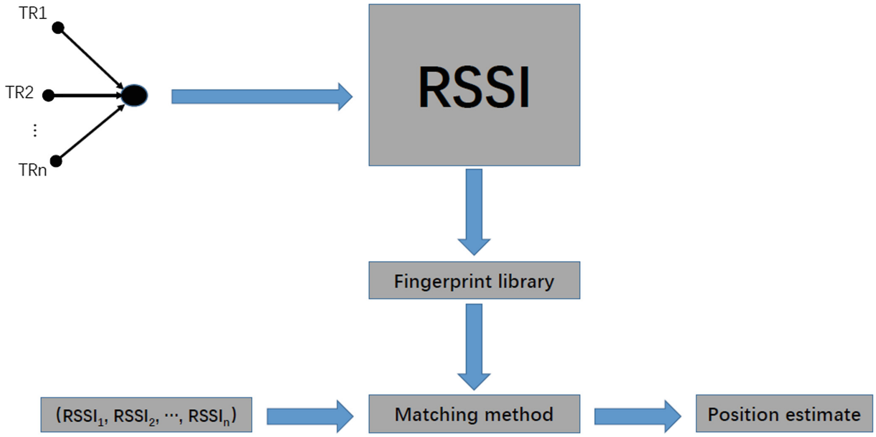

Fig. 2. Location fingerprint model location process

The two parts can be described as follows:

1. Offline fingerprint generation

Usually several transmitters are used to transmit signal continuously, simultaneously a receiver is moved onto different point to measure the signal strength and combine them into a vector to store in the fingerprint database. In the experimental area, some reference point are choses as the transmitters, position of which is precise. The receiver signal strength indication and the actual position is one-to-one mapping. The fingerprint information vector can be described as:

$$d_{(i,j)}(\tau) = \left[d_{1,j}(\tau), \cdots, d_{R,j}(\tau)\right], \tau = 1, 2, 3, \cdots, t, t > 1 \tag{20}$$

where $d_{(i,j)}(\tau)$ is the RSSI value of the j-th reference point at time t from the i-th transmitter, t is the sampling time period and R is the number of transmitters.

2. Online fingerprint matching

In this part the RSSI information of the point to be located need to be matched with the fingerprint information in the library. Firstly, the positioning area should be limited in the area in which the fingerprint information was measured. Then compare the obtained RSSI information with the information in the fingerprint library and find the best match point in the library. Finally, through specific positioning algorithm the final position of the target can be calculated.

3.4 Fusion of DOA and RSSI

Single DOA or RSSI positioning has poor precision and higher time complexity which limited by the principle of positioning. Generally fusion algorithm can combine the advantages of different algorithm [8, 9]. In this paper the DOA and RSSI fusion algorithm is used to improve the positioning accuracy of the NB-IoT network and reduce the matching time of the RSSI positioning algorithm in application.

This paper's idea is to make full use of the measurement parameters of DOA and RSSI and mainly divided into the following steps:

1. Generate an offline fingerprint library for the target area.
2. Assuming that two cluster nodes lie in (x_0, y_0) and (x_1, y_1) which is precisely known, measure the DOA of the terminal to two cluster nodes and mark them as (θ_1, θ_2) with an uncertainty parameter as (δ_1, δ_2).
3. The angle estimated by the DOA algorithm limits the range of the fingerprint information library that needs to be searched to within the range of $(\theta_1 \pm \delta_1, \theta_2 \pm \delta_2)$
4. In the restricted area of the DOA parameter, calculate the matching function for each point in fingerprint library and find best match grid in library. The matching function adapted is MAE (mean-absolute-error). It can be described as follows:

$$f_{mae} = \sum \left(mae\left(rssi_{i,j}, rssi\right) + mae\left(rssi_{i+1,j}, rssi\right) + mae\left(rssi_{i,j+1}, rssi\right) + mae\left(rssi_{i+1,j+1}, rssi\right)\right) \quad (21)$$

   where rssi is the real RSSI value measured in experiment. Function MAE is de fined as formula (22):

$$mae(x, y) = \frac{1}{L} \sum\nolimits_{i=0}^{L} |x_i - y_i| \quad (22)$$

   where L is the length of vector x and y.
5. The solution we find in the fingerprint library is a grid. Then the corresponding coordinates of the four vertices of the grid point are weighted, and the weight is the reciprocal of the MAE value, which is illustrated in formula (23). This method ensures that the smaller the error, the greater the influence on the final positioning result.

$$(\mathrm{x}, \mathrm{y}) = \sum w_{i,j} * (x_i, y_i) \quad (23)$$

   where $w_{i,j} = \frac{1}{mae\left(rssi_{i,j}, rssi\right)}$.

The NB-IoT single-side fusion positioning method with DOA and RSSI parameter is shown in Fig. 3.

3.5 Result of DOA and RSSI Fusion Algorithm

In this experiment, RSSI fingerprint library was constructed with a pitch of 5 m in the dimension of x and y. The signal attenuation model is as formula (23) shows:

$$PL = 32.44 + 20 * \log(f_c) + 20 * \log(d) \quad (24)$$

The following Table 1 gives s summary of related parameter configurations.

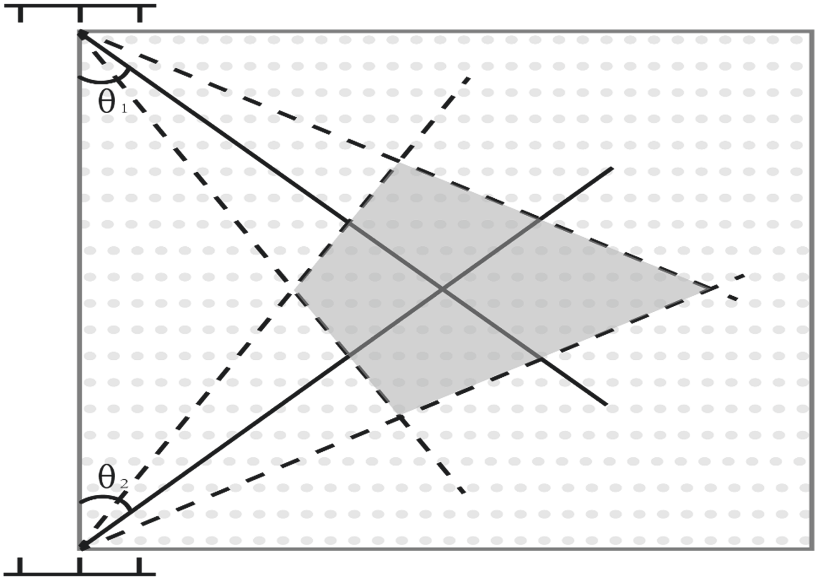

Fig. 3. DOA and RSSI fusion algorithm model

In the specific implementation of this paper, the experimental area is set to a square of 1000 m, the sampling interval of fingerprint library is set as 5 m to avoid excessive calculations and poor accuracy. Currently we consider the DOA and RSSI parameter fusion positioning algorithm of a single node. Two cluster nodes are placed at (1, 1) and (1, 1000), and the target node to be located is put in the experimental area randomly. Firstly, RSSI fingerprint library is established limited in the experimental area. Then two DOA parameters from the target node to the cluster node is measured to generate a DOA region, in which the point meets the constraints of $(\theta_1 \pm \delta_1, \theta_2 \pm \delta_2)$. Then the corresponding area in the RSSI fingerprint library is searched to find the value that minimizes the evaluate function. At last, Weighting the reference points found in the fingerprint library that meet the previous condition, the weight is the reciprocal of the MAE function and normalized. A total of 100 points of data were measured. The experimental results are shown in Figs. 4 and 5.

It can be seen from the data distribution in Fig. 4 that the positioning error of the fusion algorithm is smaller than the mean error of single RSSI positioning algorithm, and the variance is smaller. The mean and standard deviation for the data in the Figs. 4 and 5 is calculated and listed in Table 2.

From the data in Table 2, it can be seen that the average positioning error of the fusion positioning algorithm in the x direction and the y direction is much smaller than that of the single positioning method, which proved my method is effective. The performance of traditional RSSI algorithm is easily affected by interference and has a severe offset from the real position. As a contrast, the fusion Algorithm limits the area of RSSI matching by using DOA information, which reduces the impact of random interference.

Table 1. Parameters configuration

Attribute	Value
Number of cluster nodes	2
Position of cluster nodes	(1 m, 1 m), (1 m, 1000 m)
Sampling interval of fingerprint library	5 m in both x and y dimension
Antenna array	Uniform line array
Number of antennas	8
SNR	20 dB
Snapshot	512
Evaluate function	Mean Absolute Error

4 Fusion Positioning of 5G and NB-IoT

In our fusion positioning scheme, some cluster nodes were introduced to help improve the precision of NB-IoT terminal. Ideally, these cluster nodes have the ability of communicating with the 5G side and the NB-IoT side, and these functions are still in implementation by others. In the previous experiments, assuming that the location of the cluster nodes is precisely known, based on the location of the cluster nodes the DOA and RSSI fusion positioning from the cluster nodes to the NB-IoT terminals is completed. However, in actual situations, the location of the cluster nodes needs to be obtained in advance by other positioning methods, such as TDOA mentioned before.

4.1 Algorithm Description

The problem with this situation is that the error caused by the TDOA positioning of the cluster nodes is further transmitted to the next step of the fusion positioning of the NB-IoT terminals by the cluster nodes, resulting in different degrees of deterioration of the positioning results. In this part we try to reduce this impact by consider the error of cluster node positioning. Specifically, suppose the position solution of the cluster node is (x, y) and the corresponding error is (δ_x, δ_y). For the points in the solution space $(x \pm \delta_x, y \pm \delta_y)$, regard it as the position coordinates of the cluster nodes. Then DOA and RSSI fusion positioning method is used to achieve higher positioning accuracy.

4.2 Result of Fusion Positioning Algorithm

In this part, the fusion algorithm on both sides is compared with the one-side positioning algorithm. For the points in the uncertain regions generated by the cluster nodes due to the error, respectively, the NB-IoT side DOA and RSSI fusion algorithm positioning experiments are performed. The results is showed in Fig. 6 and Table 3.

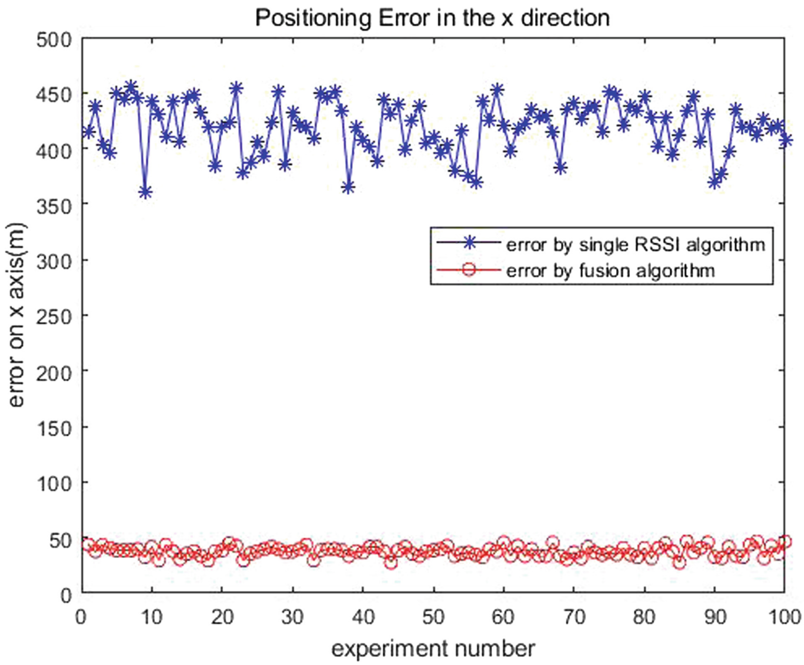

Fig. 4. Positioning Error in the x direction

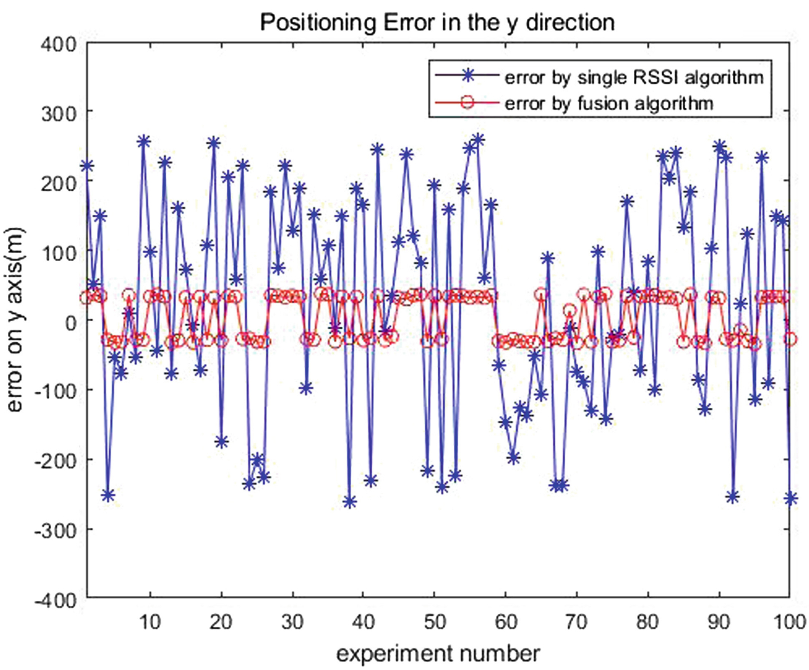

Fig. 5. Positioning Error in the y direction

Table 2. Result analysis

Direction	Algorithm	Mean	Standard Deviation
X	RSSI Algorithm	419.4068(m)	41.6814
	Fusion Algorithm	37.5169(m)	8.2867
Y	RSSI Algorithm	28.6660(m)	289.7484
	Fusion Algorithm	3.9701(m)	57.6721

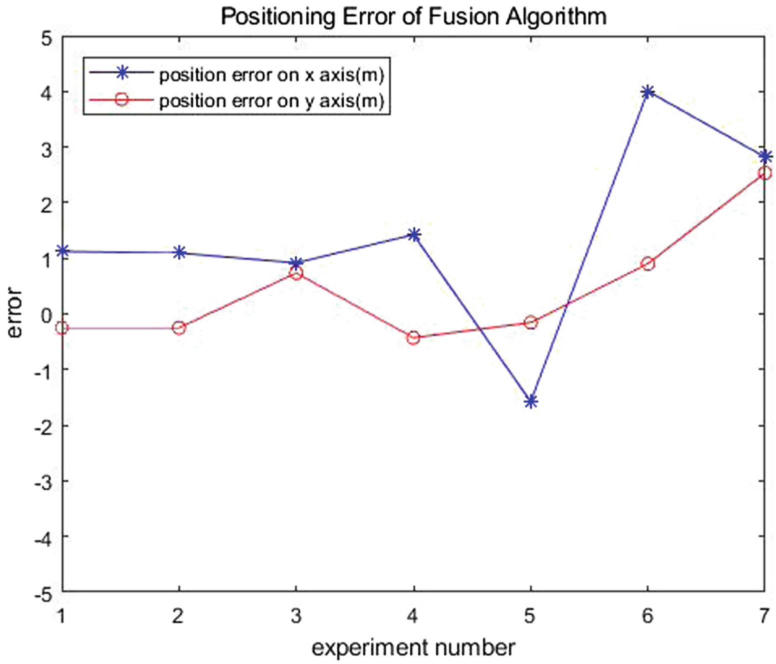

Fig. 6. Results of Fusion positioning algorithm

From the data showed in Fig. 6, we can get a conclusion that the position error is far less than that of the algorithm on NB-IoT side showed in Figs. 4 and 5. The final positioning accuracy in X direction can reach 1 m and 1 m in Y direction. The result proved that the stepwise positioning produces a local optimal solution. In the case of considering the global optimal solution, higher positioning accuracy can be obtained.

Table 3. Result analysis of fusion Algorithm

Condition	X(m)	Y(m)
Real value	482	534
Estimate value	483.1235	533.7515
Real value	517	574
Estimate value	518.0938	573.7508
Real value	487	482
Estimate value	487.9171	482.7340
Real value	558	439
Estimate value	559.4247	438.5715
Real value	466	559
Estimate value	464.4247	558.8438
Real value	570	585
Estimate value	572.8163	587.5350
Real value	574	467
Estimate value	578.0024	467.9018

5 Conclusion

In conclusion, by introducing cluster nodes, the NB-IoT single-side DOA and RSSI fusion positioning algorithm effectively improves the positioning accuracy of the NB-IoT network terminal. The average of final positioning error is less than 40 m in the x direction and less than 10 m in the y direction. In the case of strong noise interference, its performance is much better than single RSSI positioning algorithm.

In the fusion positioning experiment of the whole network, considering the error of the cluster node, the solution closer to the actual position of the point to be estimated can be obtained, and the positioning error is further reduced. In the case of strong noise, the overall solution has a mean error of 1.8504 m in the x direction and an average error of 0.7505 m in the y direction.

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References

1. GPP TS 36.211 V15.0.0 (2017-12), "Evolved Universal Terrestrial Radio Access (E-UTRA); Physical channels and modulation", Release 15 (2017)
2. GPP TS 36.355 V15.0.0 (2018-06), "Evolved Universal Terrestrial Radio Access (E-UTRA); LTE Positioning Protocol (LPP)", Release 15 (2018)
3. Liu, C., Yang, J., Wang, F.: Joint TDOA and AOA location algorithm. J. Syst. Eng. Electron. **24**(2), 183–188 (2013)
4. Lin, L., So, H.C., Chan, F.K.W., et al.: A new constrained weighted least squares algorithm for TDOA-based localization. Sig. Process. **93**(11), 2872–2878 (2013)
5. Chen, P.C.: A non-line-of-sight error mitigation algorithm in location estimation. In: IEEE Wireless Communications and Networking Conference, September 1999
6. Wylie, M.P., Holtzman, J.M.: The non-line-of-sight problem in mobile location estimation. In: 1996 5th IEEE International Conference on Universal Personal Communications, Record. IEEE (1996)
7. Hara, S., Yabu, T., et al.: A perturbation analysis on the performance of TOA and TDOA localization in Mixed LOS/NLOS environments. IEEE Trans. Commun. **61**(2), 679–689 (2013)
8. Stefano Maddio, A.C., Manes, G.: RSSI/DoA based positioning systems for wireless sensor network. In: New Approach of Indoor & Outdoor Localization Systems (2012)
9. Bayat, K., Adve, R.S.: Joint TOA/DOA wireless position location using matrix pencil. In: IEEE Vehicular Technology Conference. IEEE (2004)
10. Bnilam, N., Ergeerts, G., Subotic, D., et al.: Adaptive probabilistic model using angle of arrival estimation for IoT indoor localization. In: IEEE 2017 International Conference on Indoor Positioning and Indoor Navigation (IPIN) – Sapporo, 18 October 2017–21 October 2017, pp. 1–7 (2017)
11. Stoica, P., Arye, N.: MUSIC, maximum likelihood, and Cramer-Rao bound. IEEE Trans. Acoust. Speech Sign. Process. **37**(5), 0–741 (1989)
12. Demirbas, M., Song, Y.: An RSSI-based scheme for sybil attack detection in wireless sensor networks. In: 2006 International Symposium on a World of Wireless, Mobile and Multimedia Networks (WoWMoM 2006). IEEE (2006)