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Localization Algorithm of Indoor Wi-Fi Access Points Based on Signal Strength Relative Relationship and Region Division

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Abstract: Precise localization techniques for indoor Wi-Fi access points (APs) have important application in the security inspection. However, due to the interference of environment factors such as multipath propagation and NLOS (Non-Line-of-Sight), the existing methods for localization indoor Wi-Fi access points based on RSS ranging tend to have lower accuracy as the RSS (Received Signal Strength) is difficult to accurately measure. Therefore, the localization algorithm of indoor Wi-Fi access points based on the signal strength relative relationship and region division is proposed in this paper. The algorithm hierarchically divide the room where the target Wi-Fi AP is located, on the region division line, a modified signal collection device is used to measure RSS in two directions of each reference point. All RSS values are compared and the region where the RSS value has the relative largest signal strength is located as next candidate region. The location coordinate of the target Wi-Fi AP is obtained when the localization region of the target Wi-Fi AP is successively approximated until the candidate region is smaller than the accuracy threshold. There are 360 experiments carried out in this paper with 8 types of Wi-Fi APs including fixed APs and portable APs. The experimental results show that the average localization error of the proposed localization algorithm is 0.30 meters, and the minimum localization error is 0.16 meters, which is significantly higher than the localization accuracy of the existing typical indoor Wi-Fi access point localization methods.

Keywords: Wi-Fi access points, indoor localization, RSS, signal strength relative relationship, region division.

1 Introduction

With the rapid development of wireless networks, Wi-Fi is used more and more widely in recent years. Many places have Wi-Fi APs, such as hotels, restaurants, cafes, schools and enterprises. However, new security issues [Wang, Zheng, Chen et al. (2017); Zhou, Cai, Xiao et al. (2017); Wu, Zapevalova, Chen et al. (2018)] are arose while Wi-Fi bring great convenience to people's daily life. For example, some unruly elements use malicious Wi-Fi to push phishing advertisements and even illegally collect and steal user information. In

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some special departments and places that prohibit coverage of wireless signals, someone used illegal Wi-Fi and information hiding technology [Ma, Luo, Li et al. (2018); Zhang, Qin, Zhang et al. (2018)] to pass out the hidden information. Therefore, it is significant to carry out the research on the precise localization technology of indoor Wi-Fi APs for the purpose of protecting user privacy and doing a good job of security and confidentiality inspection.

Existing indoor Wi-Fi access points localization methods are mainly divided into two categories: one is based on location fingerprints, and the other is based on distance measurement.

The basic principle of the localization method based on location fingerprint [Yuan, Li, Wu et al. (2017)] is to abstract and formalize the description of the target indoor environment's characteristics. The RSS of each AP in different locations is used to describe the location information of the AP in the localization environment. These RSS are collected to form a location fingerprint database. Finally, the real-time measurement RSS value of the user is matched with the location fingerprint in the location fingerprint database, and the location with the best similarity is selected as the estimation location. In Koo et al. [Koo and Cha (2012)], a method called Serendipity is proposed, which collects fingerprint information by using a common smart phone and locates the AP location through dissimilarity analysis based on multi-dimensional scaling technology. In a room with 6 APs and an area of 35 m×50 m, the localization error is about 6.8 meters. In a room with 9 APs and an area of 27 m×37 m, the localization error is about 3.5 meters. In Cho et al. [Cho, Ji, Lee et el. (2012)], the influence of device diversity on fingerprint database is studied for the difference of RSS of heterogeneous devices Wi-Fi, and the localization error is reduced to less than 3 meters. The localization method based on location fingerprint needs to establish a location fingerprint library for a given indoor environment in advance, which is not suitable for inspection of a new region without a fingerprint library. When the environment is changed, the previously established location fingerprint library will no longer applicable.

To locate the target AP, this paper calculates the distance between the detection source and the target AP by analyzing the relationship of the specific physical quantities, such as time, angle, the signal strength and the distance during signal propagation, following the basic principle of the localization method based on distance measurement. For example, in Liu et al. [Liu, Darabi, Banerjee et al. (2007)], the distance between the detection source and the target AP is calculated by using the propagation time of the Wi-Fi signal, and then the location of the target AP is determined by the three circle intersection localization method. However, the algorithm requires strict clock synchronization between all detection sources and the target AP, the cost of the hardware is larger. In Shen et al. [Shen, Zetik and Thoma (2008)], the distance difference between the detection source and the target AP is calculated by using the time difference that the Wi-Fi signal arriving at different detection sources, and then the location of the target AP is determined by the hyperbolic localization method. However, the algorithm needs to ensure time synchronization of all the detection sources and hardware higher cost. In Xu et al. [Xu, Ma and Law (2008)], the location of the target AP is determined by geometric analysis by measuring the angle between two or more reference points to the target AP. However, this algorithm requires the antenna array to measure the arrival angle of the received Wi-Fi signal and it caused higher hardware costs.

Besides above three algorithms based on Wi-Fi signal arrival time, arrival time difference and arrival angle, the localization algorithm of Wi-Fi access points based on RSS ranging is also belong to the localization method based on distance measurement. The algorithm converts the received RSS into distance using the path loss model of Wi-Fi signal propagation, and then uses the localization algorithm to obtain the location of the target AP. In Koo et al. [Koo and Cha (2010)], when the path loss exponent and transmit power of signal propagation are unknown, the exponential relationship between RSS and distance is determined by linear approximation. Then the location of AP is estimated by using multi-point localization method, and the highest localization accuracy reaches 5 meters. In Varzandian et al. [Varzandian, Zakeri and Ozgoli (2013)], a non-monotonic function model of RSS and distance is proposed. Combined with modified triangulation algorithm, the location of AP is estimated using RSS, relative distance and direction information. Compared with the localization algorithms that based on location fingerprints, signal arrival time and signal arrival angle, the localization algorithm of Wi-Fi access points based on RSS ranging needs lower hardware cost and is simpler to operate, therefore, it is more widely used. However, a larger localization error is resulted due to the actual environment-sensitive parameters are included in the path loss model used in the algorithm.

In order to overcome the shortcomings of the above existing methods, this paper proposes an indoor Wi-Fi access points localization algorithm based on the signal strength relative relationship and region division. The proposed algorithm divides the region according to the length and width of the room in which the target Wi-Fi AP is located. The next candidate region is determined by comparing the relative sizes of RSS values at each reference points, the location coordinate of the target Wi-Fi AP is obtained until the candidate region is reduced below the accuracy threshold. This method can reduce the workload and the hardware cost and improving the localization accuracy of Wi-Fi AP.

The rest of this paper is organized as follows. Section II briefly analyzes the principles of Wi-Fi access points localization algorithms based on RSS ranging. The proposed indoor Wi-Fi access points localization algorithm based on the signal strength relative relationship and region division is elaborated in details in Section III, including the basic idea of the algorithm, the main steps and algorithm analysis. The experimental results are given in Section IV. Finally, this paper is concluded in Section V.

2 Structure principle introduction and analysis of Wi-Fi access points localization algorithm based on RSS ranging

The localization algorithm of Wi-Fi access points based on RSS ranging converted the received RSS into a distance according to the relationship model between RSS and distance. One of the most common RSS and distance relationship models in indoor environments is the path loss model [Rappaport (2002)]:

$$P_r = P_0 - 10\gamma \lg\left(\frac{d}{d_0}\right) + X_g \tag{1}$$

where P_r is the received signal strength that at distance d from the target AP, and the unit is dBm. P_0 is the received signal strength that at distance d_0 from the target AP(d_0 usually is 1 meter), γ is the path loss exponent, X_g is a random variable of Gauss distribution that is usually ignored when the amount of data collected is large.

After obtaining the distance from each detection points to the target AP by formula (1), the localization algorithm is used to obtain the location of the target AP.

In Le et al. [Le, Liu and Hedley (2012)], the method of the least squares is used for localization, the localization result of the target AP is calculated as follows:

$$Loc_{AP} = \arg\min_{x} \sum_{j} \left(\left\| Loc_{AP} - x_j \right\| - d_j \right)^2 \tag{2}$$

where Loc_{AP} is the location of the target AP, $x_j \left(1 \le j \le N\right)$ is the location of j detection sources, and d_j is the distance between the detection source and the target AP. In a 50 m×35 m office region, the localization accuracy of the algorithm is 50% to 2.5 meters, and more than 80% to 4.5 meters.

In Awad et al. [Awad, Al-Refai and Al-Qerem (2017)], particle swarm optimization (PSO) algorithm is used for localization, the potential location of a target AP is simulated using random particles. The objective function is as follows:

$$RMS_j = \sqrt{\frac{1}{N} \sum_{i=1}^{N} \left(\hat{d}_i - d_{ji} \right)^2} \tag{3}$$

where N is the number of detection points, d_{ji} is the distance between particle j and detection points i, and $\hat{d}_i$ is the distance between detection points i and the target AP. The location of the particle that minimizes the objective function is the final localization result of the target AP. In 50 m×50 m of the experimental region, the number of particles is 20 and the number of samples is 60, the localization accuracy of the algorithm is about 1.5 meters.

However, since the loss of Wi-Fi signals propagating in space can be affected by the transmission power, obstacles etc. Making P_0 and γ in the formula (1) vary with localization environment. In addition, the signal by multipath, scatter and NLOS and other factors interference, resulting in the same distance from the AP at different detection points on the RSS there is a big change, and even the same detection point of RSS at different time will produce greater volatility. The large error of the distance calculated in the localization algorithm of Wi-Fi access points based on RSS ranging outcomes a lower localization accuracy of such algorithms.

3 The proposed algorithm

Aiming to solve the problem pointed in Section 2 that the localization algorithm of existing Wi-Fi access points based on RSS ranging is susceptible to indoor environment interference and result in a lower localization accuracy. The localization algorithm of indoor Wi-Fi access points based on signal strength relative relationship and region division is proposed in this paper.

3.1 Main steps and basic ideas of proposed algorithm

The proposed algorithm is based on the idea of successive approximation. Firstly, the room where the target AP is located is used as the initial candidate region, and the coordinate system is constructed according to the length and width of the room. At the geometric center of the candidate region, the region is divided into four regions along the length and width directions of the room. Select a number of reference points for the dichotomy method on the region division line, the RSS values from the reference points to the target AP are measured respectively in different directions of the reference points. By comparing the measured signal strength relative relationship, the region with the largest relative value of signal strength determine as the next candidate region. The above process is repeated until the size of candidate region is reduced to below the accuracy threshold, and the coordinate of the center point of the region is used as the final localization result.

Algorithm details are shown in Fig. 1.

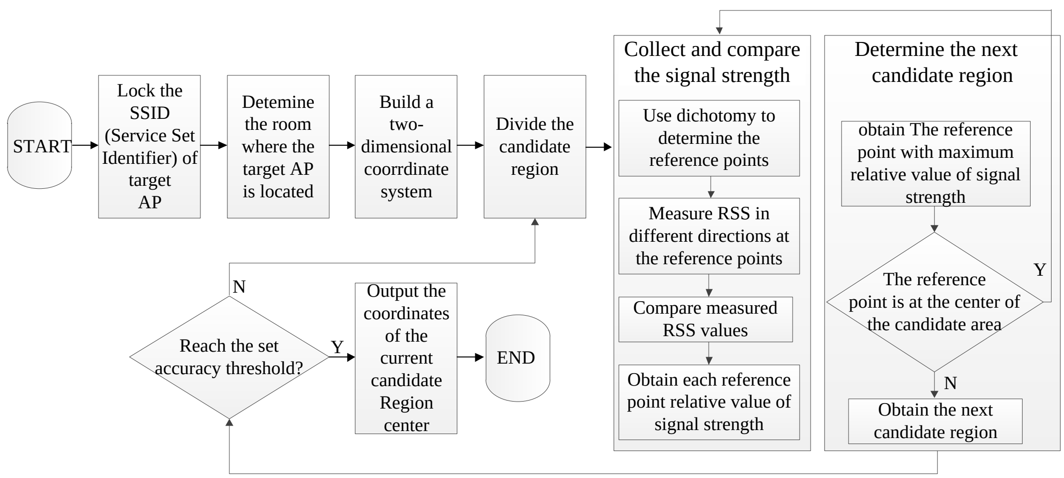


Figure 1: The flow diagram of the proposed algorithm

The main steps of the algorithm are as follows:

Algorithm input: accuracy threshold d .

Algorithm output: the coordinates of the target AP (x, y) .

Step 1: Lock the SSID (Service Set Identifier) of the target AP

Use a detection device with a wireless network card to scan nearby Wi-Fi signals to obtain a list of AP information, including AP's SSID, RSS, MAC (Media Access Control) etc. Lock the target AP according to the SSID.

Step 2: Determine the room where the target AP is located

Walking randomly in the possible rooms where the target AP exists, and the RSS from the reference points to the target AP are obtained by the detecting device. According to the change of the RSS values, the room with the largest RSS value is determined as the room in which the target AP exists.

Step 3: Build a two-dimensional coordinate system

By measuring the length l and width w of the room (or the number of room floor tiles), a two-dimensional coordinate system is constructed along the length and width of the room with one of the corner of the room as the origin of the coordinates. The room is regarded as the initial candidate region.

Step 4: Divide the candidate region

The center point of the candidate region H_i where the target AP is located (i denotes the number of times of division, and H_1 is the entire room when $i = 1$) is the origin of division, and the horizontal and vertical dividing lines are used along the length and width of the room, and the region is divided into four regions.

Step 5: Collect and compare the signal strength

Determine the three reference points with dichotomy method in the horizontal dividing line (vertical dividing line), RSS from different reference points to the target AP in different directions is measured with the signal collection device. The larger direction of each reference point RSS is obtained by comparison, and the larger RSS value is recorded as the relative value of the signal strength at the reference point.

Step 6: Determine the next candidate region

If the largest relative value of the signal strength is at the center of the candidate region, one or more reference points need to be determined with dichotomy method in the direction of the largest value on the vertical dividing line. Relative value of signal strength of each reference point is obtained, and the region where the largest relative value of the signal strength refers to as the next candidate region H_{i+1} is determined. Otherwise, the region has the largest relative value of the signal strength obtained in Step 5 is chosen as the next candidate region H_{i+1}.

Step 7: Judge whether the set localization accuracy threshold is reached

It is judged whether the current candidate region H_{i+1} reaches the localization accuracy threshold, that is to see whether l_{i+1} (l_{i+1} is half the length of the candidate region H_{i+1}) and w_{i+1} (w_{i+1} is half the width of the candidate region H_{i+1}) are less than d simultaneously. If yes, the center point coordinate (x, y) of the current candidate region is output as the localization result of the target AP. Otherwise, Step 4 is performed.

In above steps, Step 5 and Step 6 are key aspects of the algorithm. These two steps are elaborated in detail respectively in following sections.

3.2 Collect and compare signal strength

The algorithm proposed in the paper determines the location of the target AP by n times region division. The next candidate region is determined through the signal strength collection and comparison in each divided candidate region. The process of the first, second to times region division is shown as follows.

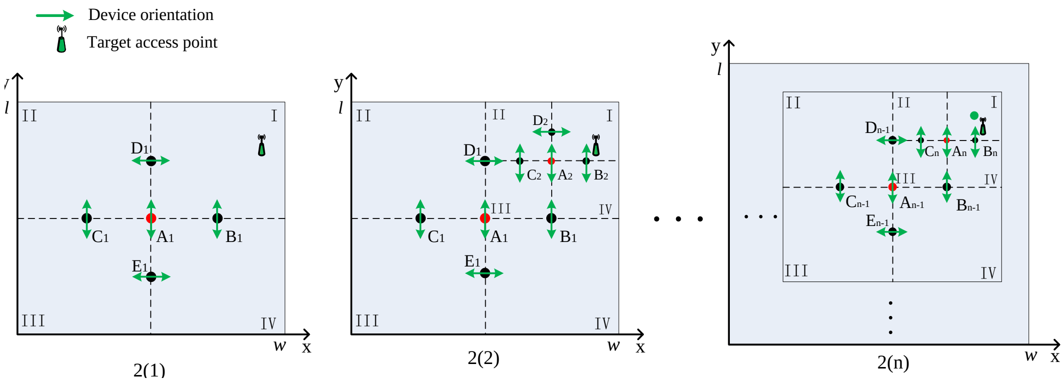
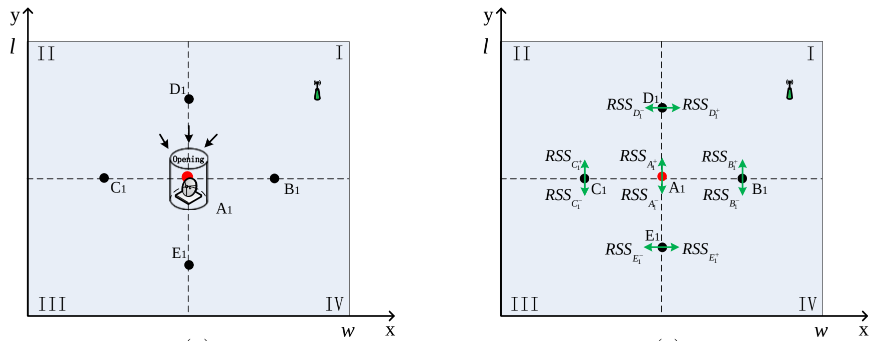


Figure 2: The diagram of the proposed algorithm

In Fig. 2, the red dot and the black dot both denote the reference points. The red dot denotes the region center point. The green arrow denotes the direction of signal strength collection. The green dot denotes the output the location of target AP.

As shown in Fig. 2, the candidate region is divided into 4 regions by the horizontal and vertical dividing lines respectively, the center of the candidate region is the original point. In the order of quadrants I to IV, they are named as $F_i^{(1)}$, $F_i^{(2)}$, $F_i^{(3)}$ and $F_i^{(4)}$, where $F_i^{(j)}$ denotes the region of the j-*th* quadrant in the i-*th* times $(i=1,2,3,...n)$ division. A_i, B_i and C_i denote the selected reference points, A_i denotes the center point of the candidate region, and its coordinate is (w_i, l_i), w_i and l_i denote the width and the length of the i-*th* candidate region respectively. The signal strength information collected at each reference point is denoted by a triples (α,β,η), where α denotes the location of the reference point and β denotes the RSS value of the from α reference point to target AP when the α reference point signal collection device towards the upper region, and η denotes the RSS value of the from α reference point to target AP when the α reference point signal collection device towards the lower region. Then the RSS of the two regions is compared, and the relative value of the signal strength at α the reference point is obtained, that is, the value of the $\max(\beta,\eta)$.

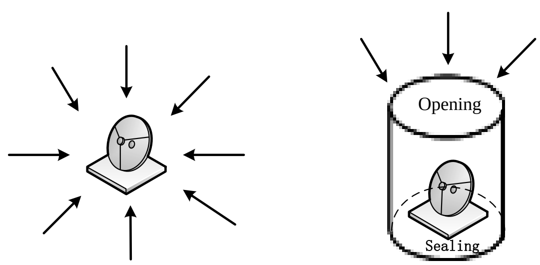
Take the first times division as an example, as shown in Fig. 3. The coordinate of A_1 is (w_1, l_1), where w_1 is half of w and l_1 is half of l. As shown in Fig. $3(a)$, the signal collection device towards the upper region at point A_1, as shown in Fig. $3(b)$ $R_{A_1^+}$ is obtained, then, $R_{A_1^-}$ is obtained when the signal collection device towards the lower region at point A_1. The signal strength triples of reference point A_1 is $\left(A_1, R_{A_1^+}, R_{A_1^-}\right)$, the relative value of signal strength $R_{A_1} = \max\left(R_{A_1^+}, R_{A_1^-}\right)$ at the point A_1 is obtained by comparing the measured signal strength values of the two regions, and can be obtained R_{B_1} and R_{C_1} similarly.



3(a) 3(b)

Figure 3: The diagram of signal strength collection process

It is worth mentioning that the signal collection device used in Fig. $3(a)$ is a modified directional antenna as shown in Fig. 4, the black arrows denote the signal direction. As shown in Fig. $4(a)$, compared with the traditional signal collection device, the modified signal collection device can shield the signal of the direction outside the open face, making the measured RSS value more accurate.



4(a) 4(b)

Figure 4: The diagram of the signal collection device

3.3 Determine the next candidate region

By comparing the relative value of signal strength of each reference point to determine the next candidate region, there are following three cases:

(1) If $R_{\max}$ is at point B_i or C_i, the region to which $R_{\max}$ points is the next candidate region.

(2) If $R_{\max}$ is at point A_i and the largest value is $R_{A_1^+}$, then it needs to be divided by using dichotomy method on the vertical dividing line above A_i to obtain the D_i reference point. If the largest value is $R_{A_1^-}$, the vertical dividing line below A_i is divided by using the dichotomy method to obtain E_i reference point. The RSS of the target AP is measured respectively in the left direction and the right direction of D_i, then the relative value of signal strength can be obtained $R_{D_i} = \max\left(R_{D_i^+}, R_{D_i^-}\right)$. Where $R_{D_i^+}$ denotes the signal

strength measured when the signal collection device towards the right region at the D_i reference point, and $R_{D_i^-}$ denotes the signal strength measured when the signal collection device towards the left region, the region pointed to R_{D_i} is determined as the next candidate region. Similarly, R_{E_i} can be obtained.

(3) If the above two cases are still unable to determine the next candidate region, then use D_i or E_i as the center point, in its two sides divided by dichotomy method, get two reference points and collecting signal strength, and comparing the collected RSS value to determine the candidate region, the region pointed to by $R_{\max}$ is the next candidate region.

The coordinates of the center points of the second division region are as shown in formula (4):

$$Loc_{AP_2}=\begin{cases}(w_1+w_2,l_1+l_2) & R_{max}=R_{B_1^+}\ or\left(R_{max}=R_{A_1^+}\ \&\ R_{D_1}=R_{D_1^+}\right)\\(w_1-w_2,l_1+l_2) & R_{max}=R_{C_1^+}\ or\left(R_{max}=R_{A_1^+}\ \&\ R_{D_1}=R_{D_1^-}\right)\\(w_1-w_2,l_1-l_2) & R_{max}=R_{C_1^-}\ or\left(R_{max}=R_{A_1^-}\ \&\ R_{D_1}=R_{E_1^-}\right)\\(w_1+w_2,l_1-l_2) & R_{max}=R_{B_1^-}\ or\left(R_{max}=R_{A_1^-}\ \&\ R_{D_1}=R_{E_1^+}\right)\end{cases} \tag{4}$$

where $w_2=w_1/2$, $l_2=l_1/2$. The center point of A_2 in Fig. 2(2), in the second times divided first quadrant, the coordinate A_2 of the center point is obtained according to the formula (4)

The $i\text{-}th$ times region division, the coordinates of the center point as shown in formula (5):

$$Loc_{AP_i}=\begin{cases}\left(\sum_{j=1}^{i}w_j,\sum_{j=1}^{i}l_j\right) & R_{max}=R_{B_{i-1}^+}\ or\left(R_{max}=R_{A_{i-1}^+}\ \&\ R_{D_{i-1}}=R_{D_{i-1}^+}\right)\\\left(w_1-\left[\sum_{j=2}^{i}w_j\right],\sum_{j=1}^{i}l_j\right) & R_{max}=R_{C_{i-1}^+}\ or\left(R_{max}=R_{A_{i-1}^+}\ \&\ R_{D_{i-1}}=R_{D_{i-1}^-}\right)\\\left(w_1-\left[\sum_{j=2}^{i}w_j\right],l_1-\left[\sum_{j=2}^{i}l_j\right]\right) & R_{max}=R_{C_{i-1}^-}\ or\left(R_{max}=R_{A_{i-1}^-}\ \&\ R_{D_{i-1}}=R_{E_{i-1}^-}\right)\\\left(\sum_{j=1}^{i}w_j,l_1-\left[\sum_{j=2}^{i}l_j\right]\right) & R_{max}=R_{B_{i-1}^-}\ or\left(R_{max}=R_{A_{i-1}^-}\ \&\ R_{D_{i-1}}=R_{E_{i-1}^+}\right)\end{cases} \tag{5}$$

where $w_i=w_{i-1}/2$, $l_i=l_{i-1}/2$, the final localization result is the location of the target AP.

The localization algorithm based on the signal strength relative relationship and region division. Using a few times the division and a small amount of reference points for the localization region to determine the final location of the target AP by comparing RSS values collected several times.

3.4 Algorithm analysis

The existing localization methods of Wi-Fi access points based on RSS ranging convert RSS to distance and obtain the target AP localization. This paper proposes an indoor Wi-Fi access points localization algorithm based on the signal strength relative relationship and region division. Successive approximation principle is adopted to overcome the problem of low localization accuracy based on RSS ranging method caused by the interference with the indoor environment. This section mainly analyzes the proposed algorithm from three aspects of localization accuracy, anti-interference and localization efficiency.

(1) Localization accuracy analysis

The main rule of the algorithm proposed in this paper is that the RSS value of the measurement is negatively correlated with the distance of the target AP. When the location of target AP is determined according to the signal strength relative relation, because of the influence of indoor environment, there may be a contradiction with the above rules, which leads to the judgment error of next candidate region and makes the localization error increase.

In this paper, the localization error of the proposed algorithm is mainly composed of two parts $\frac{\sqrt{l_i^2 + w_i^2}}{2}$ and δ:

$$\mathrm{E}_i = \frac{\sqrt{l_i^2 + w_i^2}}{2} + \delta \tag{6}$$

where $\frac{\sqrt{l_i^2 + w_i^2}}{2}$ denotes the largest distance between the location of the output target AP and the actual target AP location under the condition that the region where the target AP is located reaches the localization accuracy threshold after the limited division. The size of the room is different, the value of $\frac{\sqrt{l_i^2 + w_i^2}}{2}$ is different, when $l_i = w_i = d$, the error is largest, its value is $\frac{\sqrt{2}}{2}d$ meters.

The accuracy threshold d depends on the minimum distance between two reference points that can detect the differences of signal strength. For example, For example, a reference point is selected every 0.2 meters from 8.4 meters straight line to measure the signal strength value. The red square denotes the continuous reference point with the same signal strength as shown in Fig. 5. It can be seen from the Figure that there are at most three continuous signal strengths of the reference points is the same, that is, it cannot determine the direction of the target AP according to the signal strength relative relationship within a range of 0.6 meters, so the range of d value is $d > 0.6$ meters.

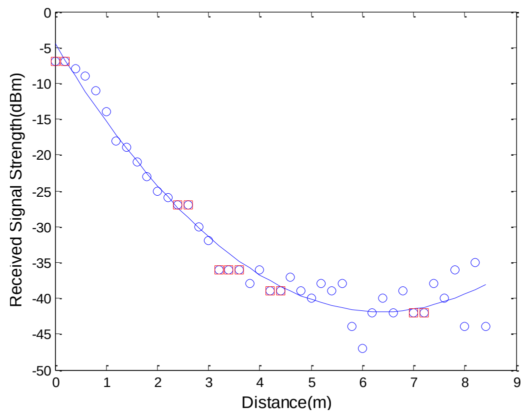


Figure 5: The diagram of signal strength and distance

δ denotes the localization error when the rule of the algorithm is not satisfied, and an example is illustrated in Fig. 6.

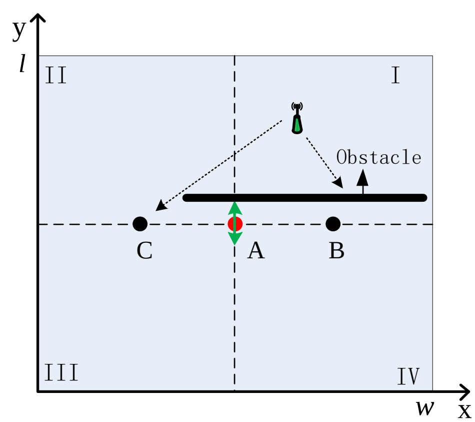


Figure 6: The diagram of region judgment error

Among them, both the black points and the red point all denote the reference points, the red point also denotes the region center point, and the black rough line denotes the obstacle. When the A, B and C reference points are measured the RSS in different directions with the signal collection device, in theory, due to B is closer to the target AP, the largest relative value of the signal strength should be at point B. However, due to the influence of obstacles, RSS received by B is decreased, which is lower than that relative value of signal strength at point C. Therefore, the next candidate region is judged to be the second quadrant not the first quadrant, which leads to the increase of the localization error, the largest error is $(w_i + \sqrt{2}/2d)$ meters, so the range of final localization error is $0 \le E_i < (\sqrt{2}d + w_i)m$.

(2) Anti-interference analysis

The existing the localization algorithm of Wi-Fi access points based on RSS Ranging use a signal collection device without directional antenna when measuring RSS. The device does not have the function of shielding signals in other directions, it will receives Wi-Fi signals from all directions, making a greater degree of interference with the finally measured RSS as shown in Fig. $4(a)$. The algorithm proposed in the paper, the direction of the target AP is determined by the signal strength value and a modified directional antenna, the device is shown in Fig. $4(b)$. The device only receives signals in a specific direction, and shields other direction signals, thereby enhancing the anti-interference ability, so that the final received RSS is less interference.

The test experiments are carried out in the general indoor environment in this paper. The experimental results show that the average difference between the RSS measured by a directional antenna and the RSS measured by the non-directional antenna is about 10dBm. Due to the 180 degree difference between the two directions of measuring RSS in the region division, environmental factors and measurement error do not affect the correctness of the results of the target AP. Therefore, the algorithm proposed in this paper is better than existing Wi-Fi access points localization algorithms based on RSS ranging in anti-interference.

(3) Localization efficiency analysis

The algorithm proposed in this paper is more localization efficient than the existing Wi-Fi access points localization algorithm based on RSS ranging. The path loss model $P_r = P_0 - 10\gamma \lg(d/d_0) + X_g$ is used in the existing localization algorithm of Wi-Fi access points based on RSS ranging. The path loss exponent γ in the formula is related to environmental factors. The algorithm needs to measure RSS and d_{ij} from N reference points to M known APs at N reference points, where d_{ij} represents the distance from the i-th reference point to the j-th known AP. Then the path loss exponent γ is calculated by the measured both RSS and d_{ij} are substituted into the path loss formula. Therefore, to improve the accuracy of the final localization result, a large number of reference points must be selected. However, the algorithm proposed in this paper adopts the method of region division, which only needs to measure RSS from reference points to target AP at a small number of reference points, so it is more efficient.

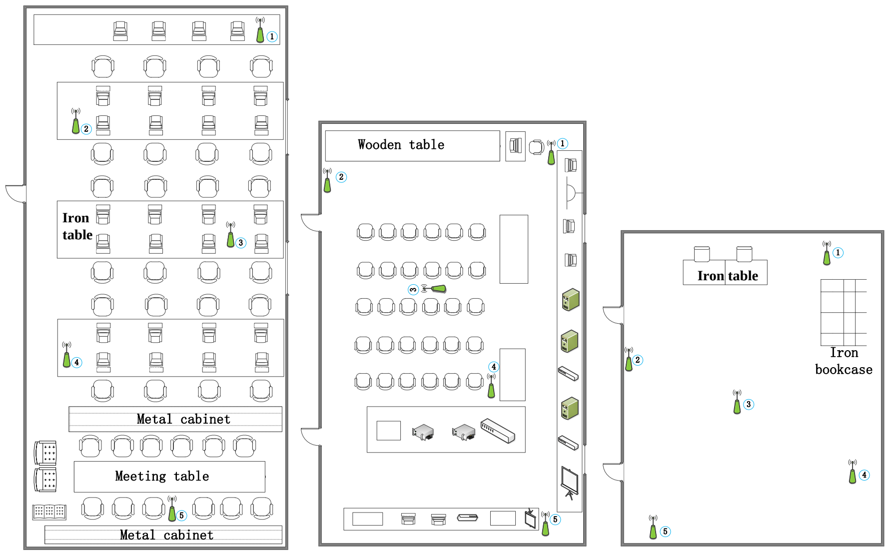
Through the analysis of the above three aspects, we can see that the algorithm proposed in this paper is more accurate than the existing Wi-Fi AP localization algorithm based on RSS ranging.

4 Expressions experimental results and analysis

In order to verify the effectiveness and feasibility of the proposed algorithm, the localization experiment is carried out several times in the actual environment. The comparison experiment are carried out on the algorithms of RSS ranging based on the least squares [Le, Liu and Hedley (2012)], the RSS ranging algorithm based on particle swarm optimization [Awad, Al-Refai and Al-Qerem (2017)] and the proposed algorithm respectively.

4.1 Experimental settings

The experiment randomly selected 5 AP locations from 3 differently-structured (including room environment and room size) rooms as shown in Fig. 7, and the size of each room is shown in Tab. 1. There are 8 different types of Wi-Fi APs in each location, including fixed APs (such as routers) as shown in Tab. 2 and portable APs (such as mobile phones) as shown in Tab. 3. A total of 360 experiments are carried out. The localization device used in the experiment mainly has a modified signal acquisition device and 8 different types of Wi-Fi APs.



7(*a*) Room A 7(*b*) Room B 7(*c*) Room C

Figure 7: The diagram of room structure

Table 1: Room structure

Room	Room size (m × m)	Floor tile length(cm)	The degree of openness	Contains objects
A	20 × 10	80	Dense and blocked	Computer, chairs etc.
B	17 × 10	80	Normal circumstances	Wooden tables etc.
C	13 × 10	60	Open	Iron bookshelf etc.

Table 2: Wi-Fi access point types (1)

Wi-Fi AP types	Fixed 1	Fixed 2	Fixed 3	Fixed 4
Models	TL-WDR6500	TL-WR842N	360 p2	AC5

Table 3: Wi-Fi access point types (2)

Wi-Fi AP types	Portable 1	Portable 2	Portable 3	Portable 4
Models	MI4LTE	Nexus5	Che1-CL20	SM-N9100

In the case that the localization accuracy threshold is set to 1 meter, the following three types of experiments are carried out to verify the factors affect the accuracy of the localization algorithms:

(1) Experiment on the influence of room structure on location algorithms.

(2) Experiment on the influence of Wi-Fi access point types on localization algorithms.

(3) Experiment on the influence of AP numbers on localization algorithms.

4.2 Experiment on the influence of room structure on localization algorithms

The experiments in this section mainly are carried out in 3 different room structures as shown in Fig. 7. The experiments are conducted using the same Wi-Fi AP at 15 target locations in 3 rooms of A, B and C respectively. The number of reference points, the actual coordinates of the APs, the coordinates of the output APs, and the localization error are shown in Tabs. 4-6.

Table 4: Test result of A room structure

The location of AP	Location 1	Location 2	Location 3	Location 4	Location 5
Number of reference points	15	15	15	15	16
The actual coordinates of the AP	(9.22, 18.44)	(4.85, 15.78)	(5.94, 14.07)	(2.03, 10.63)	(5.15, 0.83)
Output the coordinates of the AP	(9.06, 18.13)	(4.69, 15.62)	(5.94, 14.38)	(2.19, 10.63)	(5.31, 0.63)
Localization error (m)	**0.35**	**0.22**	**0.31**	**0.16**	**0.26**

Table 5: Test result of B room structure

The location of AP	Location 1	Location 2	Location 3	Location 4	Location 5
Number of reference points	12	12	12	13	12
The actual coordinates of the AP	(7.97, 16.74)	(0.16, 15.16)	(4.85, 10.09)	(6.46, 6.04)	(9.69, 0.26)
Output the coordinates of the AP	(7.81, 16.47)	(0.31, 15.41)	(4.69, 10.09)	(6.56, 5.84)	(9.69, 0.53)
Localization error (m)	**0.31**	**0.29**	**0.16**	**0.22**	**0.27**

Table 6: Test result of C room structure

The location of AP	Location 1	Location 2	Location 3	Location 4	Location 5
Number of reference points	9	9	9	9	9
The actual coordinates of the AP	(7.56, 12.08)	(0.32, 10.16)	(3.75, 6.50)	(8.44, 4.06)	(2.03, 1.02)
Output the coordinates of the AP	(7.81, 11.78)	(0.63, 10.16)	(3.44, 6.09)	(8.44, 4.47)	(2.19, 1.22)
Localization error (m)	**0.39**	**0.31**	**0.51**	**0.41**	**0.26**

As can be seen from Tabs. 4-6, the highest localization error in room A is 0.35 meters at location 1, the lowest localization error is 0.16 meters at location 4, and the average localization error is 0.26 meters. The highest localization error in room B is 0.31 meters at location 1, the lowest localization error is 0.16 meters at location 3 and the average localization error is 0.25 meters. The highest localization error in C room is 0.51 meters at location 3, the lowest localization error is 0.26 meters at location 5, and the average localization error is 0.38 meters.

The experimental results show that the required number of reference points is different for rooms of different sizes. If the room size is same and the location of the target AP is different, the required number of reference points is not necessarily the same. In addition, the room size will slightly affect the localization accuracy. The localization error range of the 120 experiments is 0.16~0.51 meters, and the average localization error is 0.30 meters.

In the 3 rooms of A, B and C shown in Fig. 7, the RSS ranging algorithm based on the least squares [Le, Liu and Hedley (2012)], the RSS ranging algorithm based on particle swarm optimization [Awad, Al-Refai and Al-Qerem (2017)] and the localization algorithm proposed in this paper are used to Wi-Fi AP localization experiments on 15 selected target AP locations respectively, the experimental results are shown in Fig. 8.

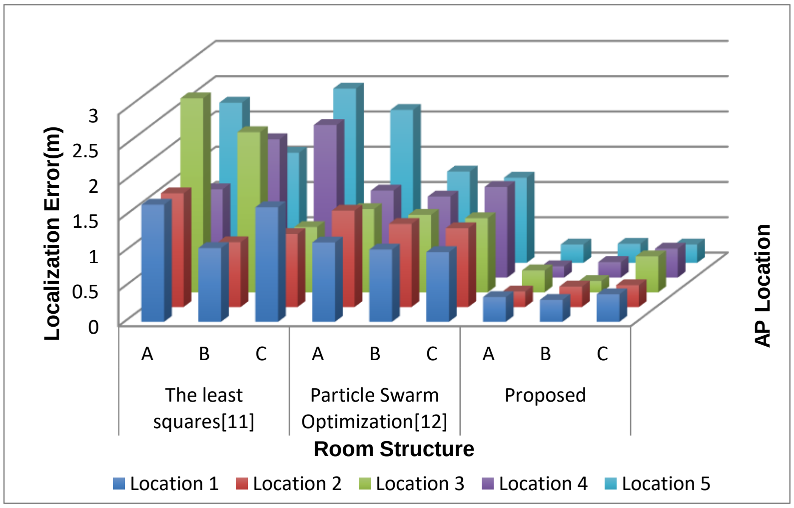


Figure 8: Influence of room structure on three algorithms

Among them, the horizontal axis denotes 3 types of localization algorithms and 3 different structures of the room. The longitudinal axis denotes the 5 AP locations arbitrarily selected in each room. The vertical axis denotes the localization error. As can be seen from the Figure that the localization error of the proposed localization algorithm in A, B and C rooms is significantly lower than the RSS ranging localization algorithm based on the least squares and the RSS ranging localization algorithm based on particle swarm optimization. The result of the localization algorithm proposed in this paper is less affected by the room structure, while the other two localization algorithms are greatly affected by the room structure.

4.3 Experiment on the influence of Wi-Fi access point types on localization algorithms

The power of different Wi-Fi AP types may be different. Therefore, 4 different types of fixed Wi-Fi APs and 4 different types of portable Wi-Fi APs are used respectively in the experiment, as shown in Tab. 2 and Tab. 3

The above 8 different types of Wi-Fi APs are placed in the 5 target locations selected in 3 rooms of A, B and C, respectively. And a total of 120 experiments are carried out. Take the experiment when the target AP is placed at location 2 in the B room as an example, as shown in Fig. 9. The Figure shows that the reference points selected for the 4 region divisions in the positioning process and the next candidate region for each division. For example, the reference points selected for the first times region division are A_1, B_1 and C_1, and the next candidate region is II Quadrant.

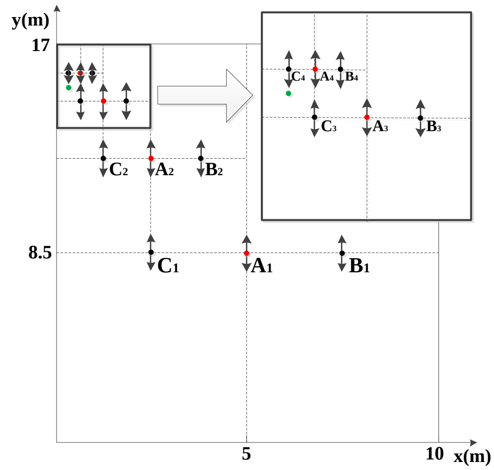


Figure 9: The process of experiment when the target AP is placed at location 2 in the B room

In the above figure, the room is 17 meters long and 10 meters wide. The coordinate system is constructed along the length and breadth of the room. The red dots denote the center location of each times division candidate region. The green dot denotes the output target AP location. The vertical black arrows denote the direction of the measured signal strength. The region pointed by the white arrow is an enlarged view of the arrow tail region.

Taking the target AP is placed at location 2 in the B room, using the 2 different types of Wi-Fi AP in Tabs. 2 and 3, respectively as an example, the signal strength triples collected are shown in Tab. 7.

Table 7: Data collected for target AP at location 2 in room B

Wi-Fi AP types	Fixed 1	Fixed 2	Portable 1	Portable 2
	$\left(A_1,-36_{A_1^+},-43_{A_1^-}\right)$	$\left(A_1,-49_{A_1^+},-52_{A_1^-}\right)$	$\left(A_1,-66_{A_1^+},-71_{A_1^-}\right)$	$\left(A_1,-69_{A_1^+},-76_{A_1^-}\right)$
	$\left(B_1,-45_{B_1^+},-47_{B_1^-}\right)$	$\left(B_1,-47_{B_1^+},-58_{B_1^-}\right)$	$\left(B_1,-71_{B_1^+},-75_{B_1^-}\right)$	$\left(B_1,-66_{B_1^+},-76_{B_1^-}\right)$
The signal strength triples	$\left(C_1,-34_{C_1^+},-48_{C_1^-}\right)$	$\left(C_1,-45_{C_1^+},-48_{C_1^-}\right)$	$\left(C_1,-62_{C_1^+},-71_{C_1^-}\right)$	$\left(C_1,-62_{C_1^+},-74_{C_1^-}\right)$
	$\left(A_2,-30_{A_2^+},-43_{A_2^-}\right)$	$\left(A_2,-34_{A_2^+},-45_{A_2^-}\right)$	$\left(A_2,-58_{A_2^+},-68_{A_2^-}\right)$	$\left(A_2,-61_{A_2^+},-68_{A_2^-}\right)$
	$\left(B_2,-32_{B_2^+},-40_{B_2^-}\right)$	$\left(B_2,-38_{B_2^+},-44_{B_2^-}\right)$	$\left(B_2,-60_{B_2^+},-65_{B_2^-}\right)$	$\left(B_2,-68_{B_2^+},-74_{B_2^-}\right)$

	$\left(C_2,-24_{C_2^+},-46_{C_2^-}\right)$	$\left(C_2,-27_{C_2^+},-48_{C_2^-}\right)$	$\left(C_2,-55_{C_2^+},-75_{C_2^-}\right)$	$\left(C_2,-54_{C_2^+},-76_{C_2^-}\right)$
	$\left(A_3,-38_{A_3^+},-42_{A_3^-}\right)$	$\left(A_3,-40_{A_3^+},-45_{A_3^-}\right)$	$\left(A_3,-56_{A_3^+},-60_{A_3^-}\right)$	$\left(A_3,-48_{A_3^+},-64_{A_3^-}\right)$
	$\left(B_3,-33_{B_3^+},-37_{B_3^-}\right)$	$\left(B_3,-33_{B_3^+},-40_{B_3^-}\right)$	$\left(B_3,-54_{B_3^+},-61_{B_3^-}\right)$	$\left(B_3,-55_{B_3^+},-67_{B_3^-}\right)$
	$\left(C_3,-27_{C_3^+},-45_{C_3^-}\right)$	$\left(C_3,-30_{C_3^+},-45_{C_3^-}\right)$	$\left(C_3,-45_{C_3^+},-65_{C_3^-}\right)$	$\left(C_3,-43_{C_3^+},-58_{C_3^-}\right)$
	$\left(A_4,-22_{A_4^+},-19_{A_4^-}\right)$	$\left(A_4,-27_{A_4^+},-24_{A_4^-}\right)$	$\left(A_4,-50_{A_4^+},-51_{A_4^-}\right)$	$\left(A_4,-47_{A_4^+},-45_{A_4^-}\right)$
	$\left(B_4,-27_{B_4^+},-24_{B_4^-}\right)$	$\left(B_4,-35_{B_4^+},-34_{B_4^-}\right)$	$\left(B_4,-50_{B_4^+},-54_{B_4^-}\right)$	$\left(B_4,-59_{B_4^+},-62_{B_4^-}\right)$
	$\left(C_4,-25_{C_4^+},\mathbf{-10}_{C_4^-}\right)$	$\left(C_4,-32_{C_4^+},\mathbf{-11}_{C_4^-}\right)$	$\left(C_4,-46_{C_4^+},\mathbf{-39}_{C_4^-}\right)$	$\left(C_4,-48_{C_4^+},\mathbf{-42}_{C_4^-}\right)$
Localization error (m)	**0.29**	**0.29**	**0.29**	**0.29**

As can be seen from the data in Tab. 5, different types of Wi-Fi APs affect RSS values at the same location, the RSS measured by the fixed Wi-Fi AP is significantly different from the RSS measured by the portable Wi-Fi AP, the RSS measured by different types of fixed Wi-Fi APs (or portable Wi-Fi APs) have little difference. In addition, the proposed algorithm is based on the geometric center of the last candidate region as the localization result, the location of the AP in the above experiment is all at location 2. Therefore, the localization error of multiple experiments should be the same when the selection of each candidate region is correct. The localization error of all the experiments in the above table is 0.29 meters, indicating the accuracy of localization results. This shows that although different types of transmitter will affect the RSS values, it does not affect the localization accuracy of the proposed algorithm.

The impact of different types of Wi-Fi APs on localization error is analyzed respectively using the RSS ranging algorithm based on least squares [Le, Liu and Hedley (2012)], the RSS ranging algorithm based on particle swarm optimization [Awad, Al-Refai and Al-Qerem (2017)] and the localization algorithm proposed in this paper. 8 types of Wi-Fi APs were used at 5 AP locations in 3 rooms during the experiments. Taking C room as an example, the experimental result is shown in Fig. 10.

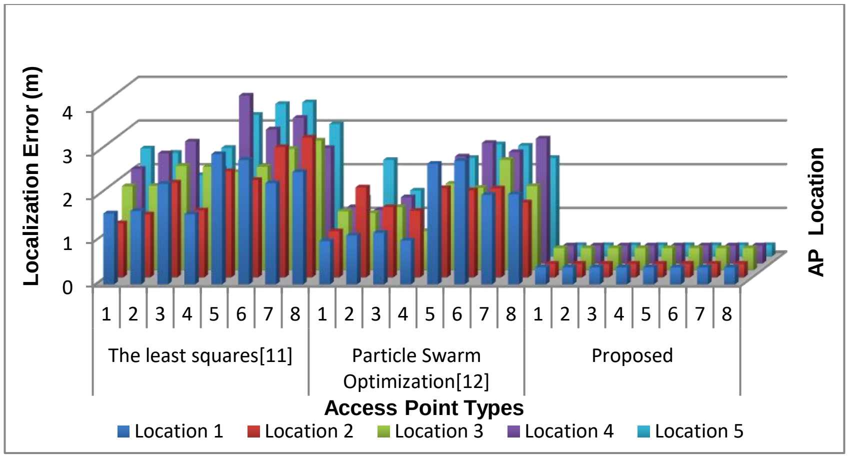


Figure 10: Influence of Wi-Fi AP Types on three algorithms

Among them, the horizontal axis denotes 3 localization algorithms and 8 Wi-Fi AP types, the longitudinal axis denotes the 5 AP locations arbitrarily selected in the C room, the vertical axis denotes the localization error. As can be seen from the Figure that the localization algorithm proposed in this paper is obviously lower than the RSS ranging localization algorithm based on the least squares and the RSS ranging localization algorithm based on particle swarm optimization, and the proposed algorithm is not affected by the types of Wi-Fi AP, while the other two algorithms are greatly affected by the types of Wi-Fi AP.

4.4 Experiment on the influence of AP numbers on localization algorithms

The algorithm proposed in this paper is not only applicable to the indoor environment with only one AP, but also is suitable for the environment with multiple APs. When there is only one AP in the room, the RSS is measured from reference points to the target AP at the reference points. The amplitude of the change is small, making the measured RSS value is relatively stable. When there are multiple APs in the room, the RSS is measured from reference points to the target AP at the reference points, the amplitude of the change is relatively large, and making the measured RSS value is not stable. Different numbers of APs are set up in 3 rooms of A, B and C respectively for experiments. Taking C room as an example, when the number of APs is different, the RSS results of the target AP measured at 1 meter, 3 meters and 5 meters respectively are shown in Tab. 8. Where Antenna 1 indicates measure using a directional antenna, Antenna 2 indicates measure using a non-directional antenna. It can be seen from the table that the number of APs will have an impact on the measured RSS value and its range of amplitudes.

Table 8: Measured data for different AP numbers

APs Number	Results	The distance of reference points to AP					
		1 m		3 m		5 m	
		Antenna 1	Antenna 2	Antenna 1	Antenna 2	Antenna 1	Antenna 2
1	RSS (dBm)	-25	-35	-36	-42	-42	-50
	Range of amplitude	-24～-28	-30～-36	-34～-39	-38～-44	-40～-45	-48～-52
2	RSS (dBm)	-28	-37	-37	-41	-44	-54
	Range of amplitude	-27～-30	-35～-40	-35～-40	-41～-47	-40～-47	-49～-55
3	RSS (dBm)	-28	-36	-37	-41	-42	-48
	Range of amplitude	-24～-30	-32～-40	-35～-40	-41～-47	-38～-47	-45～-55
4	RSS (dBm)	-26	-37	-39	-41	-41	-48
	Range of amplitude	-24～-30	-37～-43	-37～-46	-40～-48	-37～-45	-39～-53
5	RSS (dBm)	-29	-42	-40	-57	-45	-59
	Range of amplitude	-27～-33	-40～-45	-37～-42	-55～-64	-45～-51	-56～-66
6	RSS (dBm)	-29	-38	-38	-49	-46	-56
	Range of amplitude	-27～-32	-39～-42	-36～-41	-47～-53	-42～-50	-54～-62
7	RSS (dBm)	-30	-42	-41	-50	-48	-57
	Range of amplitude	-28～-34	-39～-43	-39～-45	-48～-53	-46～-50	-55～-59
8	RSS (dBm)	-30	-48	-42	-53	-48	-57
	Range of amplitude	-28～-35	-42～-54	-40～-44	-53～-57	-48～-51	-56～-62

The impact of the number of APs on localization error is analyzed respectively using the RSS ranging algorithm based on least squares [Le, Liu and Hedley (2012)], the RSS ranging algorithm based on particle swarm optimization [Awad, Al-Refai and Al-Qerem (2017)] and the localization algorithm proposed in this paper. The experimental results are shown in Fig. 11.

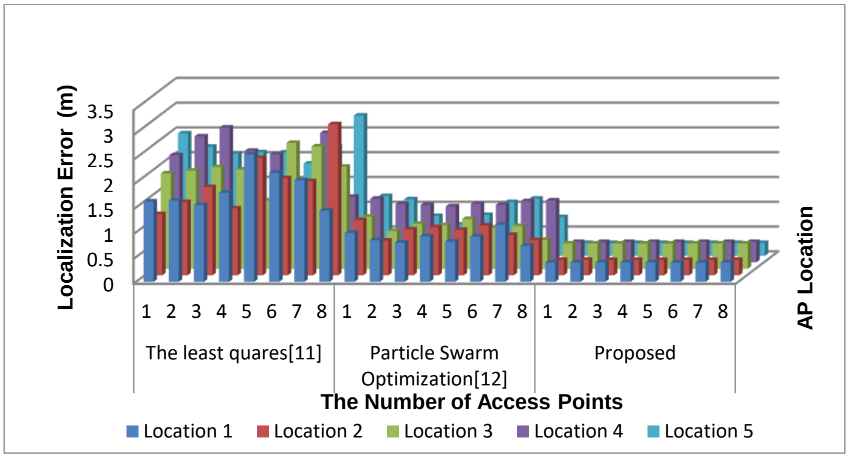


Figure 11: Influence of AP numbers on three algorithms

Among them, the horizontal axis denotes the number of APs (from 1-8), the longitudinal axis denotes the 5 AP locations arbitrarily selected in the C room, the vertical axis denotes the localization error. As can be seen from the Figure that the number of APs affects the localization error of the RSS ranging localization algorithm based on the least squares and the RSS ranging localization algorithm based on particle swarm optimization, however, the localization algorithm proposed in this paper is not affected by the number of APs.

5 Conclusion and future work

Aiming at the problem that the existing Wi-Fi access points localization algorithm based on RSS ranging has lower localization accuracy, a localization algorithm of indoor Wi-Fi access points based on signal strength relative relationship and region division is proposed in this paper. This method uses a modified signal collection device to measure the RSS of the target AP at different reference points in different directions. By comparing the RSS values, the region has the largest relative value of signal strength is determined as the next candidate region. The location coordinate of the target Wi-Fi AP is obtained when the size of candidate region is reduced to the accuracy threshold. The experimental results show that the localization results of existing Wi-Fi access point localization algorithms based on RSS ranging is susceptible to the room structure, the types of Wi-Fi APs and the number of APs. The proposed algorithm is affected less by the room structure, and is not affected by the types of Wi-Fi APs and the number of APs at all. In future work, we will focus on the research of interference of indoor specific environmental factors to the localization of Wi-Fi APs, and try to find out the exact relationship between RSS and distance. It is hoped that this research will provide technical support for researchers and staffs related to indoor localization technology of Wi-Fi AP to find the location of the target Wi-Fi AP more quickly and accurately.

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