Optimization of the Layout of WLAN Access Point Based on Location Reliability

Caiyun Deng, Ning Li

Abstract—**In the WLAN indoor location system, the layout of access point (Access Point, referred as AP) is one of key issues to improve location accuracy, present research focuses on the network coverage rate and location accuracy, without considering the effect of AP's dynamic changes on location results, for example, when one AP failures, location accuracy may decrease. In order to ensure the reliability of the system, this paper presents a method for optimizing the layout of AP based on location reliability. The method is to find out minimal number of AP and corresponding layout, when one of them failures, the rest AP can also cover all areas and location error is less than a certain value. The proposed AP's layout can greatly improve the location reliability by adding minimal number of redundant AP. The experimental results show that this method can effectively improve the location accuracy and reliability.**

Index Terms—**layout of WLAN access point, location reliability, rebundent technology, fingerprint location**

I. Introduction

At present, the research on WLAN indoor location system mainly focuses on the location accuracy and cost , such as using the selection algorithm of AP to exclude those APs in failure in order to improve location accuracy[1,2], using simulated annealing algorithm to make AP ' s number minimum as well as ensure signal covers all areas [3,4] .These studies have not taken into account the impact of the dynamic change of AP on the coverage and location accuracy, but also did not take into account the reliability of the system. When one AP is in a fault, location accuracy will be greatly reduced, the signal ' coverage will be reduced, but also can not guarantee the reliability of location. Therefore, this paper presents a method for optimizing the layout of AP based on location reliability.

II. AP's Layout Based on Location Reliability

Reliability is an important quality index to measure the system. It can improve the reliability of system by adopting the appropriate redundancy technology, but it will increase the cost of the system at the same time[5]. Therefore, the focus of this paper is to improve the reliability of the location system and to achieve the full coverage of the target area and improve the location accuracy while ensuring the number of redundant AP is minimal. The basic idea is: firstly, get the minimal number of AP that can cover all areas, and then make the reliability of the system reaching a certain value by adding redundant APs. The new AP'layout can not only cover all regions, but also can guarantee the full coverage of the signal and the average location error and the maximal location error less than a certain value when any one AP is in a failure.

In this paper, the system that can only meet the requirements of coverage and location accuracy is called non redundant system, the system that can meet the requirements of location reliability is called redundant system.

A. Optimization model of AP deployment

In this paper, the constraints for AP deployment are:

1) Signal can cover all areas.
2) The average location error is less than a certain value.
3) The maximal location error is less than a certain value.
4) The reliability of system reaches a certain value.
5) When a AP is in a fault, the signal can still cover all areas, and the average location error is still less than a certain value, the maximal location error is still less than a certain value.

The optimization objective is:

1) The number of AP for redundant systems is minimal.
2) The average location error is minimal.

In this paper, the experimental environment is setted in two-dimensional plane space, and the type of walls are the same. Assuming that the target area is S, S is divided into 1m × 1m grid, AP is deployed in a grid midpoint, the coordinate of the kth AP is defines as (X_k,Y_k), M is the number of AP and $1<=k<=M$. $D=((X_1,Y_1),(X_2,Y_2),\dots,(X_M,Y_M))$ is a certain layout of AP. The reference point(referred as RP) is in the midpoint of all grids, and the number of RP is N, (x_i,y_i) represents the coordinate of the ith RP and $1<=i<=N$.

a. Received signal strength of RP

The received signal strength (Received Signal Strength, referred as RSS) received from the kth AP at the ith RP is calculated by using the multi wall model:COST 231-MULTI-WALL MODEL [6]:

$$RSS_i(k) = RSS(d_0) + 10\times n\times \log10(d/d_0) + N_w\times L_w \quad (1)$$

In formula(1), $RSS(d_0)$ is the RSS that RP receives from AP in d_0 meters, the value of d_0 is 1; n is the path loss of the environment; d_{ki} is the distance between the kth AP and the ith RP and $d_{ki}=((X_k-x_i)^2+(Y_k-y_i)^2)^{(1/2)}$, N_w is wall number between AP and RP; L_w is the value of wall attenuation.

b. The coverage of signal

Define that the ith RP is covered: if at least one of the RSS value that the ith RP receives from all APs is larger than RSS_{min}, the ith RP is covered, and RSS_{min} is the minimal value of effective RSS, Cov_i indicates whether the ith RP is covered:

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$$\mathrm{Cov}_i=\begin{cases}1, & \exists k\in[1,M],\mathrm{RSS}_i(k)\ge \mathrm{RSS}_{\min},\\ 0, & otherwise.\end{cases} \quad (2)$$

The coverage of signal is defined as Cov:

$$\mathrm{Cov}=\sum_{i=1}^{N}\mathrm{Cov}_i \quad (3)$$

If AP must cover all areas, it needs to meet:

$$Cov=N \quad (4)$$

c. Location error

This paper uses KNN location method, each RP is tested in 50 times. the actual coordinate of the ith RP is (x_i,y_i), and (x_i^k,y_i^k) is the estimation coordinate of the ith RP in the kth location experiment, the final estimation coordinate of the ith RP is:

$$(x_i^{'},y_i^{'})=(\frac{\sum_{k=1}^{50}x_i^k}{50},\frac{\sum_{k=1}^{50}y_i^k}{50}) \quad (5)$$

The average location error of the the ith RP is:

$$\mathrm{Err}_i=\sqrt{(x_i-x_i^{'})^2+(y_i-y_i^{'})^2} \quad (6)$$

The average location error of the system is Err_{ave}:

$$\mathrm{Err}_{ave}=\frac{\sum_{i=1}^{N}\mathrm{Err}_i}{\mathrm{N}} \quad (7)$$

The maximal location error of the system is Err_{max}:

$$Err_{\max}=Max(Err_1,Err_2,\cdots,Err_N) \quad (8)$$

d. Reliability

In order to study the effect of AP's number on the reliability, this paper is based on the following assumptions: all APs are of the same type, and the failure rate is the same, the probability of failure of each AP is independent.

According to the literature[6], the relationship between the reliability function RAP and and the failure rate of AP is:

$$\mathrm{R}_{\mathrm{AP}}=e^{-\lambda t} \quad (9)$$

It can be seen from the literature[7] that for the redundant system with M AP, the probability of k AP failure at the same time is:

$$\mathrm{C}_M^{\mathrm{k}}R_{\mathrm{AP}}^{M-k}(1-R_{AP})^k \quad (10)$$

At this point, the reliability of redundant system is R_M:

$$\mathrm{R}_\mathrm{M}=\sum_{\mathrm{k}=0}^{r}\mathrm{C}_M^{\mathrm{k}}R_{\mathrm{AP}}^{M-k}(1-R_{AP})^k \quad (11)$$

In formula(11), r is the maximal number of AP that is in failure imultaneously in redundant systems. If the AP's number of non redundant system is m, then.r = M - m.

The reliability of non redundant system is R_m:

$$R_m=R_{AP}^m \quad (12)$$

Mean time between failures (Mean Time Between Failures, referred as MTBF) for redundant systems is MTBF_M:

$$MTBF_M=\int_0^\infty \mathrm{R}_\mathrm{M}dt=\frac{1}{\lambda}(\frac{1}{M}+\frac{1}{M-1}+\cdots+\frac{1}{m}) \quad (13)$$

The MTBF of a non redundant system is MTBF_m:

$$MTBF_m=\int_0^\infty \mathrm{R}_\mathrm{m}dt=\frac{1}{\mathrm{m}\lambda} \quad (14)$$

The ratio of MTBF between redundant systems and non redundant systems is defined:

$$\theta=\frac{MTBF_M}{MTBF_m} \quad (15)$$

In this paper, the AP's MTBF is taken as 10 years, and the annual failure rate is 0.1. It means that if 100 APs work continuously for one year, there 10 APs will be in a failure. R_{AP} that can be obtained by formula(9) is 0.9. In order to ensure the reliability of the system, the reliability of the system must be larger than 0.99.

B. Realization of algorithm

The problem of AP' layout is essentially a NP hard problem. In this paper, genetic algorithm is used to solve the problem of AP's layout. The design of the optimization algorithm based on location reliability is as follows:

1) Iinitiate AP'number M=1;
2) Using genetic algorithm to obtain the maximal Cov when the AP number is M ;
3) If Cov=N, then go to the fourth step; otherwise, M=M+1, go to the second step;
4) Calculate R_M when AP'number is M ;
5) If R_M>=0.99, then go to the sixth step; otherwise, M=M+1, go to the fourth step;
6) Using genetic algorithm to obtain all the D_M which meets Cov=N, Err_{ave}<3 and Err_{max}<6, and all the D_M constitute a collection of D;
7) If D is not empty, then go to the eighth step; otherwise, M=M+1, go to the sixth step;
8) Traverse the collection of D , for each D_M, calculate the correspondent indexes, including Cov, Err_{ave} and Err_{max} when anyone of the AP in D_M is in a failure one by one, if it can not meet Cov=N, Err_{ave}<3 and Err_{max}<6 at the same time, then remove the current D_M from D;
9) If D is not empty, then go to the tenth step; otherwise, M=M+1, go to the tenth step;
10) Select the smallest Err_{ave} in D as the optimal AP'layout.

The step of AP'layout is shown in Figure 1.

III. Simulation

In this paper, all tests are done in Matlab, the simulation environments are shown in Figure 2, among them, the black lines represent walls.

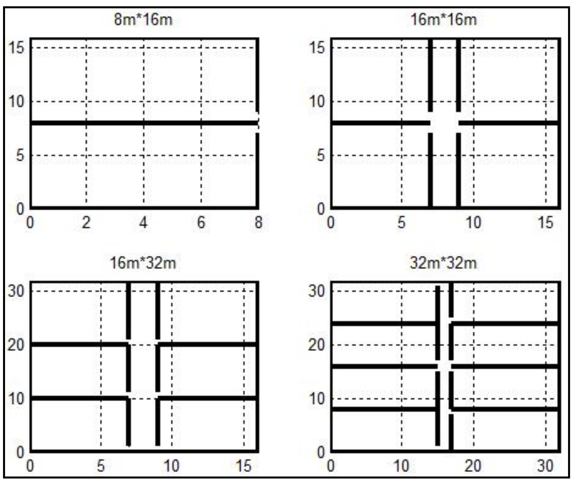

Fig. 2. Test Environments

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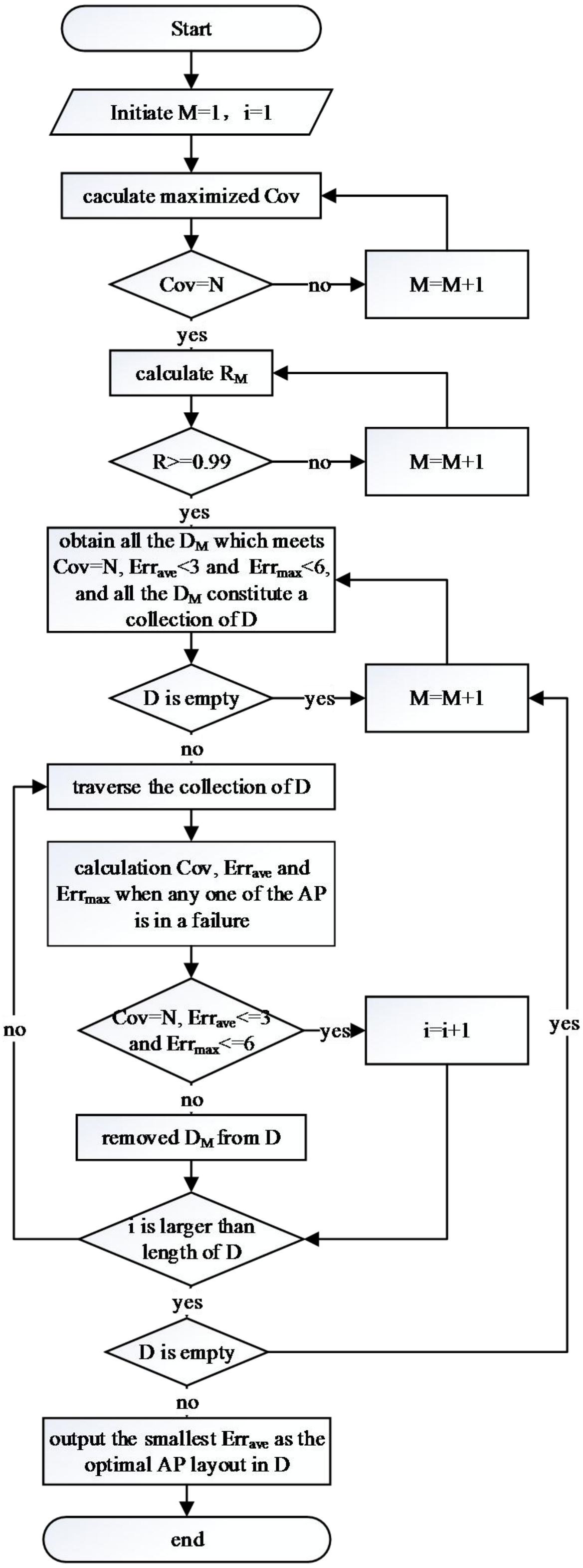

Fig. 1. AP'layout based on location reliability

Take 8m×16m for example, the minimal number of AP in non redundant system and redundant system is 1 and 2, the corresponding optimal layout of AP are shown in Figure 3.

As shown in Figure 4, the cumulative probability of the location error in non redundant system, redundant system and redundant system when anyone of AP fails in 8m×16m environment is shown. It can be seen that by adding one AP, the max location error is reduced from 6 meters to 5 meters. And the number of RP whose mean location error is under 2 meters is about 90 percentage.

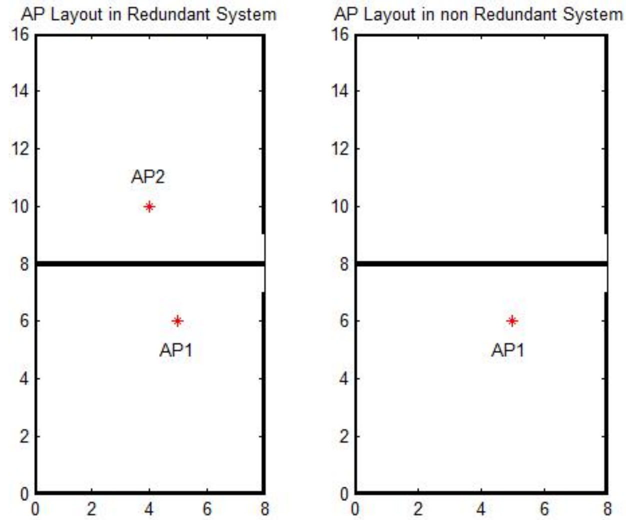

Fig. 3. AP'layout in 8m×16m

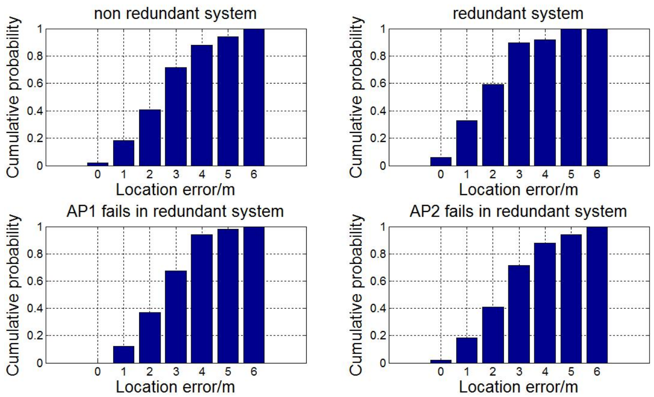

Fig. 4. cumulative probability of the location error

The following Table 1 gives the comparison results of six indexes, including AP'number(M), coverage(Cov), reliability(R), average location error(Err_{ave}), maximal location error(Err_{max}), and the ratio of MTBF(θ) in non redundant system, redundant system, anyone of AP fails in redundant system in 8m×16m.

TABLE I
COMPARISON IN 8M×16M

AP'layout / Comparison	redundant system	AP1 failures	non redundant system
M	2	1	1
Cov	100%	100%	100%
R	0.999	0.900	0.900
Err_{ave}	1.69	2.38	2.35
Err_{max}	4.12	5.79	5.90
θ	1.5	1	1

As can be seen from Table 1, the minimal number of AP that is required for non redundant system is 1, although it can meet the requirements of coverage and location accuracy, the reliability is very low. By adding 1 AP, the reliability of the redundant system reaches 0.99. Compared with the non redundant system, the average location error of the redundant system is reduced by about 28%, the maximal location error is reduced by about 30%, and MTBF is increased by a factor of 1.5. When anyone of AP in the redundant system fails, the coverage, the average location error and the maximal location error can also meet the requirements of this paper. The reliability and location accuracy of the system are greatly improved by adding 1 redundant AP. So the validity of the algorithm is proved.

The following Table 2, Table 3, Table 4 gives the comparison results of six indexes, including AP'number(M), coverage(Cov), reliability(R), average location error(Err_{ave}), maximal location error(Err_{max}), and the ratio of MTBF(θ) in non redundant system, redundant system, anyone of AP fails in redundant system in 16m×16m,16m×32m, 32m×32m.

TABLE II
COMPARISON IN 16M×16M

AP'layout / Comparison	redundant system	anyone AP fails	non redundant system
M	4	3	2
Cov	100%	100%	100%
R	0.996	0.972	0.810
Errave	1.44	2.10	2.78
Errmax	3.88	4.32	5.78
θ	2.167	1.667	1

TABLE III
COMPARISON IN 16M×32M

AP'layout / Comparison	redundant system	anyone AP fails	non redundant system
M	7	6	4
Cov	100%	100%	100%
R	0.997	0.984	0.656
Err_{ave}	1.31	1.38	1.63
Err_{max}	4.12	5.79	5.90
θ	3.467	2.467	1

TABLE IV
COMPARISON IN 32M×32M

AP'layout / Comparison	redundant system	anyone AP fails	non redundant system
M	9	8	5
Cov	100%	100%	100%
R	0.999	0.994	0.590
Err_{ave}	1.51	1.58	1.73
Err_{max}	2.82	3.42	4.22
θ	3.728	3.173	1

As can be seen from Table 2, 3 and 4, the non redundant system can meet the requirements of coverage and location accuracy, but the reliability is low. The reliability of the system can reach 0.99 by adding optimal redundant AP. When AP's number reaches more than 3, the increase of average location accuracy is relatively flat, but the MTBF is increased by at least 2 times. When a fault occurs in redundant system, the areas can also be completely covered, and the location accuracy and MTBF can be improved. In Table 4, when the AP'number is 8, the reliability of the system is greater than 0.99, but there is a large mount of walls in the environment, the attenuation of signal is high, when anyone of AP fails, it may not guarantee complete coverage of the signal, so 8 is not the optimal number of AP. The feasibility of the algorithm is proved by the above results.

IV. CONCLUSION

In this paper, optimization of WLAN AP's layout is proposed to improve the location reliability and accuracy by appropriately increasing the number of redundant AP. By increasing the minimal number of AP , the reliability of the system can reach 0.99, MTBF can be increased by at least 50%, and when anyone of AP fails in redundant system, it can still meet the requirement of coverage and sufficient accuracy. Simulation results verify the effectiveness of the proposed algorithm. The algorithm is valuable for the practical application of WLAN location system.

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