AP Deployment Optimization Based on Bluetooth Fingerprint Database Discrimination

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Abstract. In indoor fingerprint positioning system, Access Point (AP) deployment costs a lot of manpower and time, and the deployment efficiency of existing methods is extremely low due to the complexity and dynamics of indoor environment. In order to solve this problem, this paper proposes an optimal AP deployment algorithm. First of all, wireless signal propagation model is established from indoor environment. Then simulated fingerprint database is constructed based on initial AP deployment. Finally, greedy algorithm is selected to optimize the deployment of APs. The experimental results show that this method can be well adapted to the indoor environment with higher accuracy compared to the empirical AP deployment.

Key words: indoor positioning, fingerprint database, access point deployment, greedy algorithm, signal propagation model

1 Introduction

With the rapid development of wireless communication technology and the increasing demand for positioning service, wireless positioning technology has received a lot of attention [1]. In open environment, Global Position System (GPS) can provide high-precision positioning information [2]. In indoors, due to the blockage of building, walls, windows, doors, various decorations and the movement of pedestrian, received GPS signal are extremely weak and unstable, which causes valid information required for positioning can not be obtained. Therefore, experts and scholars consider establishing a positioning system based on indoor environment. At present, main indoor positioning algorithms are generally divided into following categories: fingerprint location method [3], triangulation method [4], time of arrival method [5] and angle of arrival method [6]. The fingerprint location method has been widely used with the advantages of high feasibility, portability and no additional equipment. In fingerprint positioning system, traditional AP deployment method needs to survey site and deployment plan is given according to experience. This method is time-consuming and labor-intensive, and there is often constant error in deployment results.

Based on above problems in AP deployment, this paper presents a AP deployment method based on greedy algorithm [7]. Firstly, initialize AP deployment

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and construct a simulation fingerprint database. Next, select the discrimination of simulation database as target function, move the single AP in four directions of real physical coordinates and achieve local optimal deployment of a single AP. Repeat the above steps until the fitness of deployment can not be improved anymore, and the deployment coordinates of APs are output result. Experiments show that the method can improve the efficiency of AP deployment method and the positioning accuracy of system.

The rest of paper is organized as follows. Section 2 reviews some previous work related to AP deployment. In section 3, we introduce principle and scheme of optimal AP deployment in detail. Section 4 shows experimental result. Finally, section 5 provides conclusion.

2 Related work

In recent years, the fingerprint positioning system has been widely developed. However, AP deployment consumes too much time, and AP deployment will affect the validity of fingerprint database. Therefore, it is necessary to study AP deployment algorithm based on indoor positioning system. At present, there are mainly two ways for deploying AP. One is manual survey deployment method. Another way is to deploy AP through computer-aided software. This second method is more effective than manual deployment, and it also reduces the cost. So in nowadays, the mainstream deployment of AP is based on the computer. In [8], several methods are used to solve optimization model simultaneously. Simulation results of simulated annealing method and the genetic algorithm are approximate, but the paper is mainly based on the deployment of indoor base stations covered by the signal seamlessly and does not involve the AP deployment of indoor positioning system. In [9], the Multi-Objective Genetic Algorithm (MOGA) is used to solve the problem of AP placement in WLAN system. However, the genetic algorithm has high complexity and the coding method is too complicated. As the search space increases or the number of AP increases, optimization efficiency will be greatly reduced.

The main contribution of this paper is to provide an optimal AP deployment method. Given known environmental information, the method could output AP deployment coordinates through simulation algorithm. The method has a relatively low algorithm complexity, running time, and labor costs, but also improves efficiency and positioning accuracy.

3 Algorithm description

The overall block diagram of optimal AP deployment system is shown in Fig. 1, which includes simulation fingerprint database construction module and optimization algorithm module. The database construction module includes the training of propagation model and the setting of AP position. The first step,

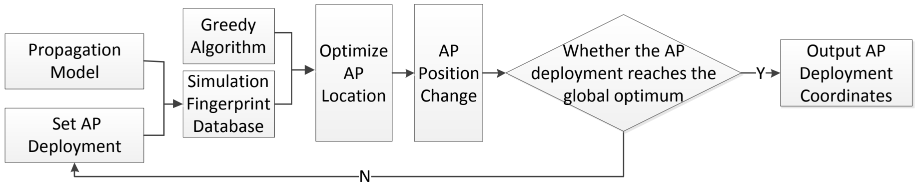

Fig. 1. The flow chart of the proposed AP deployment system.

we need to set the location of those APs randomly, and then constructs simulation fingerprint database through propagation model. The second step is to combine simulation fingerprint database with optimization algorithm to preliminarily optimize the location of AP through an improved greedy algorithm. The third step is to combine preliminarily optimized AP location and propagation model to construct a simulation fingerprint database, and then continue to iterate through the second and third steps until AP deployment solution can be optimized anymore, then output final AP location result.

3.1 AP deployment

The plan includes simulation fingerprint database construction and AP deployment optimization.

Emulation Fingerprint Database Construction: The propagation of wireless signal in an open indoor environment conforms to logarithmic decrement model. With the increase of transmission distance, the signal attenuation rate decreases gradually. In open area, the signal attenuation model [10] is

$$B_{\mathrm{ij}} = PLr[dB] + 10k\log(d_0) \tag{1}$$

where $PLr[dB]$ represents the signal strength value at one meter from AP, k indicates the attenuation factor of wireless signal in this environment, and d_0 indicates distance between reference point and AP.

The attenuation factor k is related to environment. To use signal attenuation model, we need to test k and $PLr[dB]$. The typical test environment concludes corridors and halls. Therefore, we use Bluetooth positioning system to collect data in two kinds of environments, and use least square method to do data fitting. At last, we determine the value of k is -2.5 and the value of $PLr[dB]$ is -53 in the corridor environment. Similarly, in hall environment k equals to -2.3 and $PLr[dB]$ equals to -53.

In the simulation fingerprint database construction phase, we need to determine the size between reference points. If the dimension between reference point is too small, the cost of manpower and time will be increased, and workload will be increased. Taking above aspects, the interval between reference point is set 1 m.

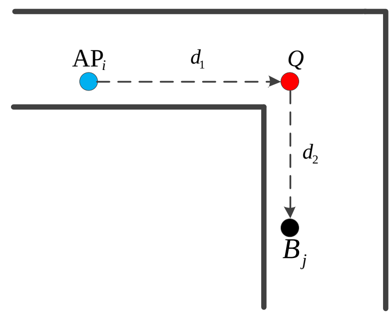

Fig. 2. An example of using virtual source.

In addition, in the database construction phase, it is necessary to consider whether there is an obstacle between reference point and AP. In both cases, the propagation model used is different. The following are the analysis of these two cases.

In first case, AP and reference point are in a Line-Of-Sight (LOS) environment. According to the simple attenuation model of wireless signal, signal strength value at reference point B_j is

$$B_{\text{ij}} = PLr[dB] + 10k\log(d_0) \tag{2}$$

where $PLr[dB]$ represents the signal strength value at one meter from AP, k indicates the attenuation factor of wireless signal in this environment, and d_0 indicates the distance between reference point B_j and AP_i.

In second case, AP and reference point are in Non-Line-Of-Sight (NLOS) environment. We propose the concept of virtual source Q. When AP and reference point are in NLOS environment, we will use virtual source. And Fig. 2 is an example of using virtual source. The signal strength value at the reference point B_j is expressed as

$$B_{\text{ij}} = PLr[dB] + 10k\log(d_1 + d_2) \tag{3}$$

where $PLr[dB]$ represents the signal strength value at one meter from AP, k indicates the attenuation factor of wireless signal in this environment, d_1 is the distance between virtual source Q and AP_i, and d_2 is the distance between virtual source Q and reference point B_j.

Based on the location of initial the deployment of APs and in combination with the calculation of signal strength in above two cases, all reference points in positioning area are traversed to establish an emulation fingerprint database.

AP deployment optimization algorithm: The greedy algorithm [11] is a graded approach that can get the optimal solution under a certain metric. It always makes the optimal choice under current conditions driven by objective function. Greedy strategy is not considered as a whole, the choice of it is made only in a sense of local optimal solution algorithm.

We use greedy algorithm for optimizing the deployment of APs. The others in [12] proposed the concept of fingerprint database discrimination, and the paper found that increasing the discrimination of database can improve the tolerance of positioning system to the fluctuation of signal. Therefore, in this paper, we use largest discrimination as an objective function. The objective function of process is as follows.

$$\alpha = \{(X_1, Y_1), (X_2, Y_2), \cdots, (X_p, Y_p)\} \tag{4}$$

where p is the number of AP; $\{(X_1, Y_1), (X_2, Y_2), \cdots, (X_p, Y_p)\}$ is the position coordinates of AP, α is a placement of AP. The simulation fingerprint database is set up under the deployment, and the sum of the p dimension signal intensity of the i-th reference point is obtained. Euclidean distance of signal at i-th reference point is $\overline{l_i}$, which is shown as

$$\overline{l_i} = \sum_{j \in O(i)} \left\| \overline{RSS_i} - \overline{RSS_j} \right\| \tag{5}$$

where $\overline{RSS_i}$ is the RSSI mean vector of the i-th reference point, $O(i)$ is a set of reference points that satisfy that physical distance to the i-th reference point is less than L, which is set as 2 m.

Then we traverse all reference points and obtained the average value F_1 of signal intensity of all reference points in Euclidean distance. F_1 is shown as

$$F_1 = \frac{1}{n} \sum_{i=1}^{n} \overline{l_i} / length(O) \tag{6}$$

where n is the total number of reference points, $length(O)$ is the number of elements in set O. Then, calculate the difference between the average Euclidean distance of signal at all reference points and standard deviation, and we call it the discrimination F_2, which is shown as

$$F_2 = F_1 - \left(\sum_{i=1}^{n} \left(\overline{l_i} - F_1 \right)^2 \right)^{1/2} \tag{7}$$

In the process of algorithm, larger F_2 has lager discrimination, and the AP deployment result is better.

Among them, the specific implementation of algorithm is described as follows: first of all, number each of AP and place APs evenly in the area. Then, move AP_i in reference point of positioning area. And rely on objective function, we optimize result to update the maximum discrimination F_2 and reach local optimum. Then we perform same operation for the remaining APs. At this point, the deployment of each AP has reached a local optimal state. Next, perform same operation from AP_1 to AP_p. The stopping condition of algorithm is the discrimination F_2 can not be updated. And then the system outputs recommended AP deployment coordinates. The pseudo code of algorithm is shown in Fig. 3.

Algorithm:	AP deployment optimization
INPUT:	AP initial deployment
OUTPUT:	Recommend the AP deployment coordinate

```
Random AP deployment
max F_2 ← 0
While (1)
    i ← 1
    for each AP_i ∈ AP_s do
        While (1)
            Move the AP_i coordinates and updated F_2
            If (F_2 reaches the maximum )
                AP_i reaches the local optimum
                break
            end
        end
        i ← i+1
    end
    If ( max F_2 − F_2 == 0 )
        AP deployment reaches the global optimum
        break
    else
        max F_2 ← F_2
    end
end
Output suggested AP deployment coordinates
```

Fig. 3. Pseudo-code of AP deployment.

4 Experimental Results

To investigate the performance of proposed approach, we use the Bluetooth positioning system for online positioning test. We select TI company's CC2540 as its built-in chip and OnePlus A5010 mobile phone as terminal equipment. At the same time, we design an application for the acquisition of RSSI and the application uploads data to server periodically.

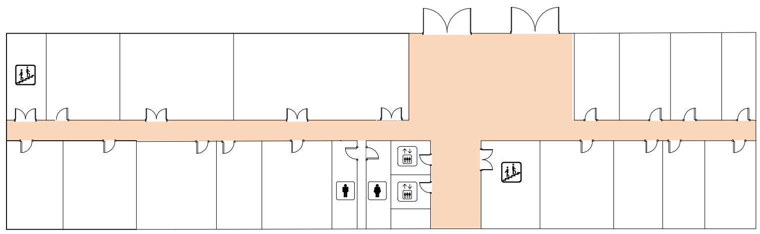

Fig. 4. Physical layout of target environment.

The positioning test mainly consists of two phases, the first phase is offline phase, the second phase is online phase. The offline phase is mainly to collect fingerprint database under the condition of AP deployment, including dividing positioning area, selecting reference point, collecting the signal intensity value of a single reference point, and constructing fingerprint database. The online phase is mainly to walk in a set line and collect the intensity of Bluetooth signal.

The test site is the first floor of a building. The area is a typical office area with offices, corridors, and halls. The flat map is shown in Fig. 4, the orange part is test area, with a total area of about 374 m^2 and there are 8 BLE anchors in the area.

Fig. 5 shows the location of AP deployment based on empirical approach. Fig. 6 shows the location of AP deployment based on proposed approach. Among them, the experience of deployment is into the scene of the deployment of environmental exploration results. We carried out data collection, database building and location analysis for these two different deployments respectively. And select a track for Bluetooth positioning test. Fig. 7 is the Cumulative Distribution Function (CDF) based on fingerprint database in two different deployments. It can be seen that under two different deployments, the positioning accuracy of optimal deployment is higher than the positioning accuracy of experience deployment. Therefore, the deployment method proposed in this paper is better than the experience of deployment.

In the above test environment, we use the WKNN [13] algorithm. From the positioning results, the positioning accuracy of two different deployments both meet user's demand for daily location. And the positioning accuracy of optimal deployment is higher than the positioning accuracy of experience deployment. Obviously, this method improves the efficiency of AP deployment and positioning accuracy.

5 Conclusion

In view of high cost and low efficiency of AP deployment in previous indoor positioning technology, an optimal AP deployment for indoor Bluetooth positioning is proposed in this paper. The experimental results show that this method can improve the efficiency of AP deployment, save time cost to a large extent, and

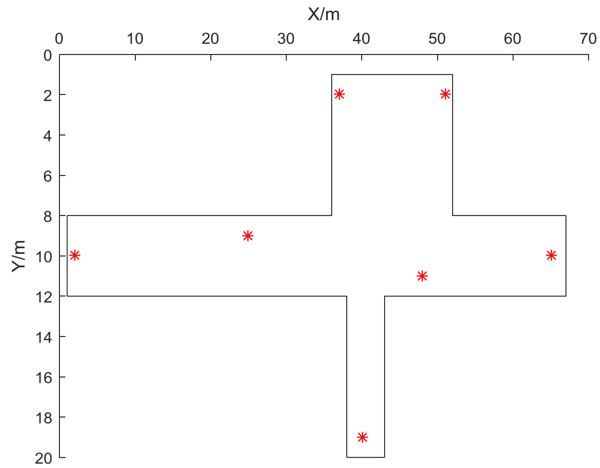

Fig. 5. AP deployment result based on experience.

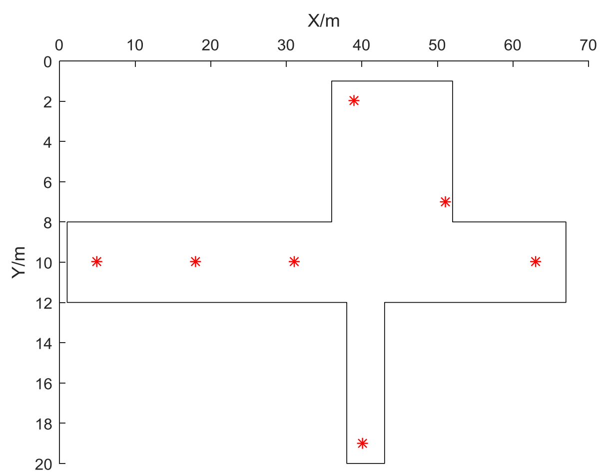

Fig. 6. AP deployment result used algorithm.

improve positioning accuracy. It is worth mentioning that this method improves the tolerance of signal fluctuation with the increase of discrimination of fingerprint database.

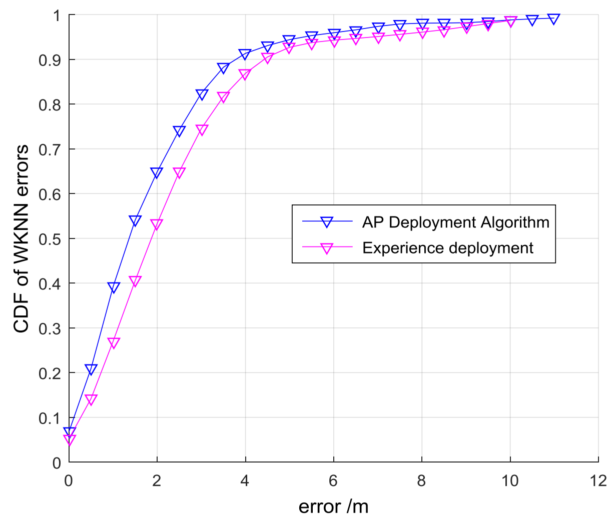

Fig. 7. CDF of BLE positioning errors with the fingerprint database.

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