Access Point Location and Trajectory Tracking Method based on the Weight Update

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ABSTRACT**:** *In recent years, wireless access technology is quite popular for its convenience, fast and flexible. However, due to the openness of wireless network, this technology also faces with a number of secure challenges, one of which is how to deal with the unauthorized access point effectively. As we all know, the unauthorized access point leads to not only increasing interference between signals induced by the fierce competition of wireless channel resources, but also data leakage resulting in "wireless phishing". In response to these security threats, much importance has been put on the research of unauthorized access point location and trajectory tracking. This paper firstly proposes an optimization model of wireless signal propagation. Then an access point location and tracking method called APL_T is put forward, which supports three-dimensional location based on the weight update improving the location accuracy effectively and raises the trajectory tracking of the access point in the light of the three-dimensional location. Finally, the experimental results show that APL_T has a high accuracy and can meet practical requirements.*

Keywords: Wireless Network, Wireless Location, Trajectory Tracking, Weight Update, RSSI

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1. Introduction

Wireless network technology gains rapid growth and begins to be applied to enterprises, government departments, private households and other fields. It brings a lot of convenience for working, studying and everyday life. However, the wireless LAN uses air as the transmission medium, which introducing greater difference in access control, authentication and other security technologies compared with the traditional LANs whose transmission medium are cables. The wireless LAN is easy to cause data leakage resulting in "*wireless phishing*" and other information security issues. Among these issues, unauthorized access points (APs) problem are particularly prominent, which affect national security, network security, privacy and economic security. Therefore, unauthorized APs problem has become one of the most important security issues that affect the security of wireless LAN.

The APs (Access Point) are major wireless LAN access equipments. The unauthorized APs are illegal wireless access points without the authorization [1].

The unauthorized APs are divided into two categories. The one is built by the staffs of companies. The APs cannot be monitored by the network security system, through which the malicious users can invade the internal network, and bring a huge security risk to the internal networks [2]. The other is the malicious users to get users' information by a variety of means of attack to paralyze and destroy the wireless LAN. In this case unauthorized APs are used to create a fake wireless LAN, when users access this fake wireless LAN, the malicious users can intercept the information of users through wireless transmission networks, and engage in criminal activities such as theft of state secrets, commercial secrets and personal privacy and so on.

The unauthorized APs are hazardous in the following aspects.

(1) The malicious ones use the software tools such as mdk2 to fake AP signals, which occupy the regular channels and interfere with the normal radio communication [3].

(2) The unauthorized APs can intercept the wireless network communication data, invade personal computers, divulge personal information such as personal privacy and personal electronic account information.

(3) The unauthorized APs can be built on the internal networks inside the companies and bring the serious threats to the network security.

(4) The unauthorized APs will consume the limited resources of the wireless network.

(5) The unauthorized AP will bring the problem of the co-channel interference.

In summary, it is important to accurately locate and track the unauthorized APs, by which we can manager, control, or remove the unauthorized APs conveniently.

The rest of the paper is organized as follows. We briefly review the related works in Section II and present an optimization model of wireless signal propagation in Section III. In Section IV, we describe an access point location and tracking method named APL_T. We show that the scheme can achieve fairness, and we present the evaluation results in Section V. Finally, we conclude the paper and point out potential future works in Section VII.

2. Related Research

2.1 Wireless Location Method

The domestic and foreign scholars have studied the wireless location methods for a long time.

Reference [4] presents the location method based on the time of arrival (TOA) which uses the propagation of electromagnetic waves to measure the distance between the transmitter and the receiver. Assuming the propagation time of electromagnetic waves from the beacon nodes to the mobile nodes is t. Since the speed of light is equal to the speed of wave, the speed of wave is c. So the distance between the beacon node to the node needed to be located is $t \times c$. Because the speed of light is very fast, TOA is very sensitive to deviations.

Reference [5] introduces a location method based on the signal arrival of angle (AOA). It uses an antenna array to estimate the angle of arrived signals, and locates the unknown node by the angles. An angle of the source can be got by an AOA measurement. If we get effective measurements of two or more different places, the location of the signal source can be determined out by the intersecting of two angles. Usually, we can use multiple AOA values of different locations to improve the accuracy of measurements. The indoor environment is complex. The walls, the plants and the other obstructions will affect the propagation of radio signals. Because of reflection, refraction, multipath propagation and multipath interference, AOA-based location method is not suitable for indoor wireless location.

Reference [6] introduces a location method based on time difference of arrival (TDOA). It reduces the requirements for the clock synchronization, and it locates moving objects by measuring the time difference of arrival between two base stations. The moving object is located on the hyperbolic whose focus are the base stations. To locate the moving object, we need at least three base stations, and create two hyperbolic equations. Then we can solve the equation to obtain the position coordinates of the moving object. However, due to ultrasonic propagation distance is limited, the network must be densely built. Compared with TOA-based location method, this method is more convenient to use, and it can be accurately located. The TDOA-based method also be affected by multipath propagation and NLOS propagation.

Reference [7] introduces a location method based on the Received Signal Strength Indication (RSSI). The basic idea of this location method is as follows: if the transmission power of the transmitting node is already known, we measure the received power at the receiving node, and calculate the propagation loss of the signal. We turn the propagation loss into the distance by the theoretical model of the signal propagation, then we can use the triangular location method or the maximum likelihood method to locate the receiving node. The method does not require high performance hardware, and its algorithm is relatively simple. In the experimental environment, this method has a good performance. However, due to changes in environmental factors, it often needs to be improved in practice. The main reason for the deviation is reflection, multipath propagation, non-line dissemination and so on.

Reference[8] introduces a range-free location method. This me-thod does not measure the absolute distance and the angle between nodes, but it calculates the location of nodes by using the network connectivity information. algorithms of the range-free method include the centroid algorithm, the dv-hop algorithm, the amorphous location algorithm, the convex programming location algorithm and so on.

2.2 The Challenges of the Wireless Location

Nowadays the wireless location technologies is confronted with many difficulties and challenges. How to eliminate these negative factors and improve the location accuracy will determine whether the wireless location can be widely used and developed.

1) The multipath propagation is one of the basic factors that affect the wireless location. In the mobile channel, for the presence of the reflectors and scatterers, there will be an ever-changing network environment which makes various signal energy in the amplitude, phase and time latency [8].

2) Another important factor which leads to deviation is the non-line of sight (NLOS) signal between beacon nodes and receiving nodes Line of sight (LOS: Line of Sight) propagations are necessary to obtain accurate measurements of signal characteris-tics, but in cities and suburbs, LOS propagations between beacon nodes and the receiving nodes are usually very difficult [9].

3) Users of wireless networks are all using the same frequency band. The high-performance network also have troubles with proximity effect and MAI [10].

4) The number of beacon nodes used for location is limited. Location technologies generally require at least two or three beacon nodes.

3. Access Point Location and Trajectory Tracking Method Based on the Weight Update

3.1 The Optimization Model of Signal Propagation

The propagation distance of the wireless signal is related to the transmission power, the receiver sensitivity and the operating frequency. Assuming d is the transmission distance, its unit by km, f is card working frequency, its unit by MHz, Lfs is the transmission loss, its unit by dBm, and n and c are constants. We can get as follow.

$$Lfs = c + 10n \lg d + 10n \lg f \tag{1}$$

Assuming the transmission power of the wireless device is F, units by dBm. $P(d)$ is the received signal strength when the signal transmission distance is d, units by dBm. Because the signal transmission loss = transmission power – the received signal strength, we can get:

$$Lfs = F - P(d) \tag{2}$$

From the equation (1) and the equation (2) we can get:

$$F - P(d) = c + 10n \lg d + 10n \lg f \tag{3}$$

When the signal transmission distance is d_0, we can get:

$$F - P(d_0) = c + 10n \lg d_0 + 10n \lg f \tag{4}$$

From the equation (3) and the equation (4) we can get:

$$P(d) = P(d_0) - 10n \lg (d / d_0) \tag{5}$$

When d = 1m, $A = P(d_0)$ is the received signal strength when the signal transmission distance is 1m. Assuming n is the propagation attenuation constant. Equation (5) can be expressed as:

$$P(d) = A - 10n \lg d \tag{6}$$

Equation (6) is used to calculate the signal propagation distance in free space. But in reality, we have to consider such factors as obstacles. Σ *WAF* means the impact of all the obstacles, we can get:

$$P(d) = A - 10n \lg d - \Sigma WAF$$

3.2 The Access Point Location

In order to describe the proposed location method, we give the following definitions.

Definition 1. Anchor Node: It is also called beacon node, the node which can locate itself by some way.

Definition 2. Unknown Node: Its location cannot be known in advance. We need to use the location information of the anchor nodes, and some algorithms to calculate its location.

If we want to locate an unknown node in the three-dimensional space, we need to use at least four anchor nodes. As shown in Figure 1.

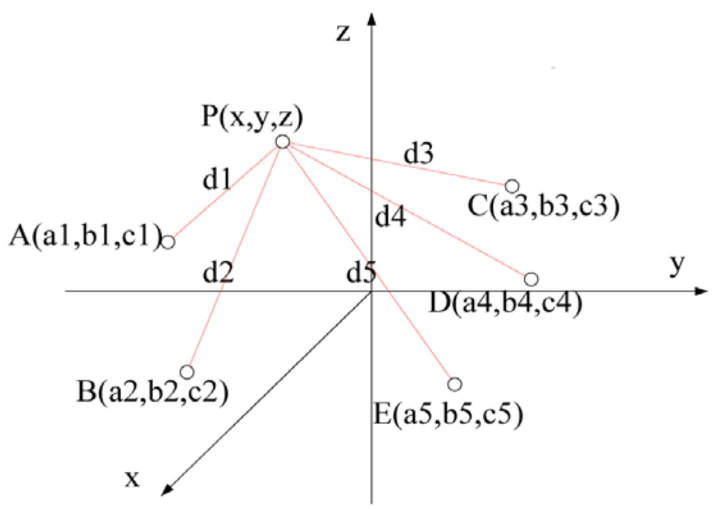

Figure 1. The space coordinate diagram

A, *B*, *C*, *D* is the anchor nodes, and *P* is the unknown node. Assuming that RSSI1 is the signal strength of the node *P* received by node *A*. Assuming that RSSI2 is the signal strength of node *P* received by node *B*. Assuming that RSSI3 is the signal strength of node *P* received by node *C*. Assuming that RSSI4 is the signal strength of node *P* received by node *D*. Assuming that RSSI5 is the signal strength of node *P* received by node *E*. According to the relationship between RSSI and distance, we can calculate the distance between the anchor nodes and the unknown node. Assuming that d1 is the distance between *A* and *P*. Assuming that d2 is the distance between *B* and *P*. Assuming that d3 is the distance between *C* and *P*. Assuming that d4 is the distance between *D* and *P*. Assuming that d5 is the distance between *E* and *P*.

Using any four distances between the anchor nodes and point *P*, we can calculate the theoretical coordinates *P*1, *P*2, *P*3, *P*4 of point *P*. Finally, we calculate the average of these four theories coordinates as the coordinate of *P*.

Having four anchor nodes to locate an unknown node, the most common mathematical method is the least squares method. However, the least squares method leads to large deviations in practical. So we proposed a least squares method based on weight update.

Assuming (x, y, z) is the coordinates of the unknown node. The coordinates and the RSSI of four anchor nodes are:

$$(a_1, b_1, c_1), RSSI_1;$$
$$(a_2, b_2, c_2), RSSI_{21};$$
$$(a_3, b_3, c_3), RSSI_{31};$$
$$(a_4, b_4, c_4), RSSI_{40};$$

We can turn equation (6) to equation (7):

$$RSSI = A + 10n \lg d \tag{7}$$

By the equation (7), we can calculate four distance information respectively d_1, d_2, d_3, d_4.

$$\begin{aligned}
&(x - a_1)^2 + (x - b_1)^2 + (x - c_1)^2 = d_1 \\
&(x - a_2)^2 + (x - b_2)^2 + (x - c_2)^2 = d_2 \\
&(x - a_3)^2 + (x - b_3)^2 + (x - c_3)^2 = d_3 \\
&(x - a_4)^2 + (x - b_4)^2 + (x - c_4)^2 = d_4 \\
&r^2 = d_i^2 - (a_i^2, b_i^2, c_i^2) \\
&i = 1, 2, 3, 4 \\
&R^2 = x^2 + y^2 + z^2
\end{aligned} \tag{8}$$

Equation (8) is converted to:

$$\begin{bmatrix} -2a_1 & -2b_1 & -2c_1 & 1 \\ -2a_2 & -2b_2 & -2c_2 & 1 \\ -2a_3 & -2b_3 & -2c_3 & 1 \\ -2a_4 & -2b_4 & -2c_4 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ r^2 \end{bmatrix} = \begin{bmatrix} r_1^2 \\ r_2^2 \\ r_3^2 \\ r_4^2 \end{bmatrix} \tag{9}$$

Assuming；

$$Q = \begin{bmatrix} -2a_1 & -2b_1 & -2c_1 & 1 \\ -2a_2 & -2b_2 & -2c_2 & 1 \\ -2a_3 & -2b_3 & -2c_3 & 1 \\ -2a_4 & -2b_4 & -2c_4 & 1 \end{bmatrix}, \theta = \begin{bmatrix} x \\ y \\ z \\ R^2 \end{bmatrix}, b = \begin{bmatrix} r_1^2 \\ r_2^2 \\ r_3^2 \\ r_4^2 \end{bmatrix}$$

Equation (9) is converted to:

$$Q\theta = b$$

We get the result by the least squares method:

$$\hat{\theta} = (Q^T Q)^{-1} Q^T b$$

3.3 The Access Point Trajectory Tracking

we further establish tracking model based on location. Assuming that the target i do uniform motion in a certain period of time, then we can create the tracking model as equation (10) shown.

$$x_i(k + 1) = f(k)\, x_i(k) + rw(k) \tag{10}$$

Assuming r is the propagation radius of the particle. At time k, assume that $w(k)$ is the white Gaussian noise of particles. Its average value is 0. We further get:

$$x(k) = \begin{bmatrix} x_1(k) & v_{x1}(k) & y_1(k) & y_{y1}(k) \\ x_1(k) & v_{x2}(k) & y_2(k) & y_{y2}(k) \\ \vdots & \vdots & \vdots & \vdots \\ x_n(k) & v_{xn}(k) & y_n(k) & y_{yn}(k) \end{bmatrix} \quad (11)$$

In equation (11), $x(k)$ is the state vector. $(x_t(k), y_t(k))$ is the location of the unknown node at time k. $(v_x(k), v_y(k))$ is the speed of the unknown node at time k. t is the interval.

$$f = \begin{bmatrix} 1 & t & 0 & 0 & 1 & 0 & 0 & t & \ldots \\ 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & \ldots \\ 0 & 0 & 1 & t & 0 & 0 & 1 & t & \ldots \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & \ldots \end{bmatrix} \quad (12)$$

Observation equation based on the theory of particle filter can be represented by equation (13).

$$z(k+1) = \tan^{-1}(\hat{y}(k+1) / \hat{x}(k+1)) \quad (13)$$

In equation (13), $(\hat{x}(k+1) / \hat{y}(k+1))$ is the location of the unknown node at time

We will adopt the predictive filtering method and the data association method. When there is more than one unknown node aggregating in the same area, it would result in relevance between unknown nodes. As a result we need to consider the interaction between unknown nodes, and use cross-motion tracking algorithm for this case. By this way we can solve the association problem between the measured values and objectives probabilistic data. First, we determine the matrix by calculating the relationship between the location of the unknown node and tracking range. Ωw_j^i $(i = 0, 1 \ldots m_2)$ is represented by the equation (14).

$$\begin{bmatrix} 1 & w_1^1 & w_1^2 & \ldots & w_1^n \\ 1 & w_2^1 & w_2^1 & \ldots & w_2^1 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ 1 & w_{m_2}^1 & w_{m_2}^1 & \ldots & w_{m_2}^1 \end{bmatrix} \quad (14)$$

w_j^i is a binary variable. w_j^1 means that the unknown node j is within the tracking range of anchor node. w_j^0 means that the unknown node j is not within the tracking range of anchor node. Assuming n is the quantity of detected unknown nodes. Assuming m_k is the quantity of detected nodes after data fusion.

Confirm matrix reflects the relationship between measured values and unknown nodes. Then we can get feasible joint events and corresponding index, which depends on two basic assumptions. First, assuming that the only source of the signal strength is either unknown node or a clutter. Each unknown node has at most one measured value whose source is the unknown node itself. By stratified searching the signal strength of the unknown nodes, we can find the index that every possible event corresponding.

So the associated probability between the signal strength and unknown nodes can be expressed as equation (15).

$$\beta_k^{j,i} = P(\theta_k^{j,i} / Z(k)) = \sum_{j=1}^{n_i} P(\theta_{k,i} / Z(k))\, w_j^i(\theta_{k,i}) \quad (15)$$

We present data integration with data association method based on particle filter .the random produced by the noise and the multipath makes the value of the node tracking range very random. So we use the idea of the particle filter optimization to each measurement value within the tracking range of anchor nodes. Then we integrate the data using probabilistic data association, update particles, and determine the location and status of the unknown node at the next moment.

4. Performance Analysis

We use the Matlab software to simulate this location and trajectory tracking method. We built five anchor nodes, and their communication radius is 20m. The monitoring distance is half of the communication radius, and the sampling period is 5s. The initial location of the target is (0, 0), and the amount of the effective particles N are 2 and 4.

Omitting the fixed obstacle, the distance can be calculated by equation (6). First we need to calculate the equation parameters A and n.

$A = P(d_0)$ means the received signal strength when the distance between the unknown node and anchor nodes is 1 meter. anchor nodes scan channels once per minute, and collect the transmission signal strength of anchor node. We counted the results 50 times, and got the distribution about $A = P(d_0)$ to calculate its average value. which is –40dBm.

As A is already known. we set the distance between anchor nodes and the unknown node 2m and 3m respectively. The unknown node scan the channels once per minute and collect the transmission signal strength of anchor nodes. We counted the results 120 times. When $d = 2m$, we calculate that $P(d_2) = -49$ dBm. According to equation (6), we can get $n_2 = 3.08$. When $d = 3m$, we calculate the result that $P(d_3) = -55$ dBm. According to equation (6), we can get $n_3 = 3.12$. At last,the average value of n is 3.1.

In summary, the signal propagation model can be presented by equation (16).

$$P(d) = 40 - 311g\, d \tag{16}$$

We collect multiple sets of data to analyze the performance of the model. Part of the data show in Table 1.

RSSI value (dBm)	Distance Calculated (m)	Actual Distance (m)	Deviation (m)
62	6.404	5.2111	1.1929
73	11.6016	10.1482	1.4534
79	18.1161	20.3068	2.1907
80	22.5129	25.8971	3.3842
90	41.0113	34.313	6.6 983

Table 1. The Relationship between Distance and Deviations

Data in Table 1 reflects the relationship between RSSI values and distances, it also reflects the relationship between the deviation and distances. Obviously, deviation increases as distance increases.

Using several experiments data, we compared the location data with and without weight updating on. The experimental data is shown in Figure 2.

5. Conclusions and Future Work

The paper proposes a wireless signal propagation optimization model firstly. Then we propose an access point location and tracking method APL_T (Access Point Location and Trajectory Tracking Method based on the Weight Update). APL_T supports three-dimensional location based on the weight update, which effectively improves the accuracy of location. APL_T further get the trajectory tracking of the access point, the experiment result demonstrates the effectiveness of the method.

APL_T is primarily used for the location and trajectory tracking of a single target. However, there is usually more than one target appears in a wireless network environment at the same time. So we will study how to solve the problem of multi-targets location and tracking as well as the problem of multi-targets trajectory cross-cutting in the future.

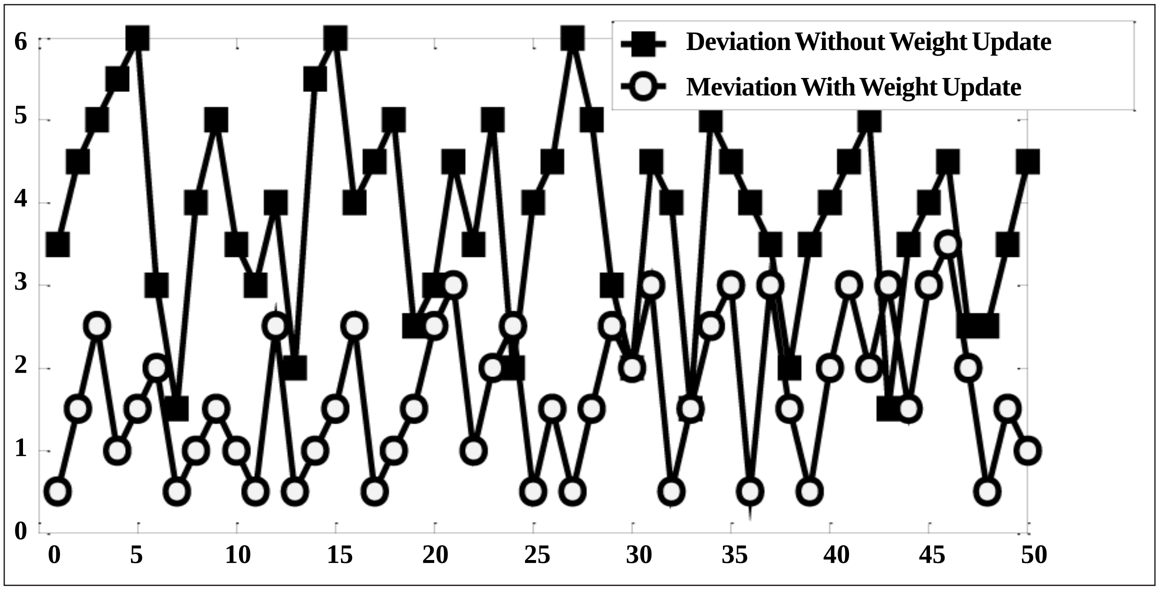

Figure 2. The Positioning accuracy comparison

6. Acknowledgment

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