Accuracy Improvement using WLAN for Indoor Positioning Systems

Ye Tian, Wenjian Wang and Chang-Jun Ahn

***Abstract*—** At present, the theory and algorithm of wireless indoor positioning systems have been widely researched. Some applications of these systems have been successfully used such as inventory management. Nevertheless, positioning using radio signals indoor is subject to multipath propagation and other causes. Therefore, how to determine the location accurately has been recognized as a difficult task. This paper focuses on one of the positioning methods called received signal strength indication (RSSI) in a Wireless Local Area Network (WLAN). To improve the positioning accuracy, we proposed a scheme which to estimate the distance between access point (AP) and mobile station (MS) using the average of pilot signal strength in frequency domain. We then propose another scheme to estimate the position of the MS utilizing a weighted least-squares (LS) method. At last, the simulations results show that the proposed schemes have a higher degree accuracy compared with the conventional methods.

***Keywords*—**indoor positioning, RSSI, frequency domain, weighted LS method.

I. Introduction

IN recent years, there is an increasing demand in accurate location finding techniques and location-based applications for indoor areas. Global Positioning System(GPS) which is a space-based satellite navigation system address the issue of geolocation outdoor [1]. However, due to the severe signal attenuation cased by construction materials, GPS cannot provide accurate geolocation indoor. Therefore, the theory and algorithm of indoor positioning systems have been widely researched.

Accurate indoor geolocation is an important technology for commercial and public safety [2]. In commercial applications such as in nursing homes and residential quarter, indoor geolocation systems can be used to track the elderly, and children who are away from supervision, to navigate the blind, and to find specific goods in warehouse. In public safety applications there is an increasing need to track inmates in prisons prisons and navigating fire fighters and policeman to complete their missions indoors [3].

Geolocation using radio signals have several conventional techniques which include the time-of-arrival (TOA), time-difference-of-arrival (TDOA), angle-of-arrival (AOA) and received signal strength indication (RSSI) based schemes [4], [5]. For TOA-based systems, the distance from the mobile station (MS) to base stations (BSs) is directly proportional to the propagation time. In order to enable the position of the MS, the MS and BSs in the TOA-based systems have to be precisely synchronized. Rather than the absolute arrival time of TOA, TDOA-based systems are to determine the position of the MS by examining the difference in time at which the signal arrives at multiple BSs. For TDOA-based systems, synchronization among BSs is required. In AOA-based systems, the location of the MS can be found by the intersection of several pairs of angle direction lines which formed by the circular radius from a BS to th MS. AOA Measurements can be made without the requirement of synchronization. However, for the above three schemes, geolocation accuracy can be severely degraded in the indoor environment caused by lack of line-of-sight (LOS) path [6].

In recent years, many commercial and residential establishments are already equipped with wireless access-point (AP) and most mobile devices are wireless enabled. Most of these devices can measure received signal strength as part of their standards. Therefore, the most common geolocation method is the RSSI technology in a WLAN, which has low communication load and low complexity [7]. Many research efforts have been devoted to this region for more reliably and more accurately. In RSSI-based systems, two steps are needed to accomplish the geolocation. The first step is to calculate the propagation loss according to the strength of transmitting signals from the APs and that of receiving signal from the MS, and then utilize a radio propagation channel model to estimate the distances from APs to MS. The second step is to estimate the location of the MS basing on the known locations of APs and the estimated distances.

In this paper, two novel schemes are proposed to accomplish the RSSI-based geolocation systems more accurately. Firstly, we propose a novel method to estimate the distances between APs and the MS using the average of pilot signal strength in frequency domain. And then, a novel weighted least-squares algorithm is proposed to estimate the location of the MS. The rest of this paper is organized as follows. Section II shows the conventional distance estimation method based on RSSI, and the conventional location estimation method of the MS. In section III we proposed two novel schemes to estimate the distances from APs to MS and the location of the MS, respectively. Simulation results are presented in Section IV. Finally, section V concludes the paper.

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II. Conventional Positioning Methods

A. Conventional distance estimation method

Under idealized condition, the Friis transmission equation is used to calculate the power received by one antenna transmitted from another antenna some distance away. Suppose P_t is the power of the transmitted signal, P_r is the power of the received signal, d is the distance between the transmitting node and the receiving node, λ is the wavelength and the antenna gains of the transmitting and receiving antennas are G_t and G_r, respectively. The Friis transmission equation is defined as

$$P_r = G_t G_r (\frac{\lambda}{4\pi d})^2 P_t \quad (1)$$

In most cases, G_t, G_r, P_t, and λ are known parameters. Therefore, under idealized conditions, d can be calculated as

$$d = \frac{\lambda}{4\pi}\sqrt{\frac{G_t G_r P_t}{P_r}} = \frac{\lambda}{4\pi}\sqrt{\frac{G_t G_r}{\alpha}} \quad (2)$$

Where α is the ratio of transmitted power to received power. However, in the indoor conditions, the receiving power is interfered with severe multipath and specific site parameters such as floor layout, moving humans and numerous reflecting surfaces. For the indoor conditions, suppose P_r' is the power of the received signal, H is the channel response, N is the additive Gaussian white noise(AGWN). Then we have

$$P_r' = \alpha H P_r + N \quad (3)$$

The conventional method, named as RSS-based method, determine α by utilizing the ratio of the mean of P_t to P_r', which results in large errors. Therefore, it is crucial to find a method to estimate α accurately.

B. Conventional location estimation method

In WLAN based systems, after estimate the distances between APs and the MS, the location of the MS will be estimated utilizing the geometric properties of triangles conventionally. In order to enable 2-D positioning, measurements must be made with respect to signals from at least three APs [8] as shown in Fig. 1.

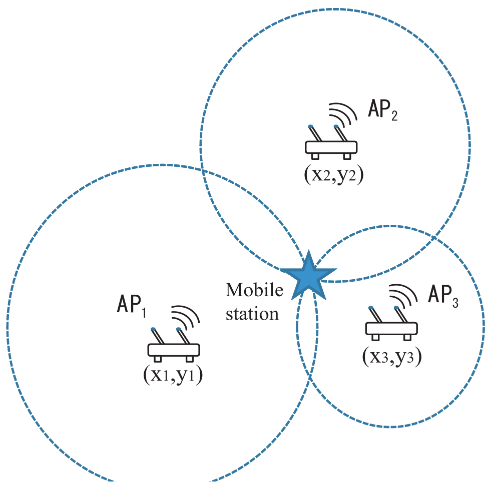

Fig. 1. Positioning under ideal condition

Under idealized condition, there is one intersection point of the circles with radius of estimated distances and centered at APs. However in practice, there will be several intersections due to the errors in distance estimations. In this case we can take the average of these intersections to estimate the location of the MS. Suppose (a_1,b_1), (a_2,b_2), (a_3,b_3) are the intersections of the circles centered at AP_1, AP_2 and AP_3, respectively. The position of the MS is determined to (A,B), as shown in Fig. 2.

$$A = \frac{a_1 + a_2 + a_3}{3}, B = \frac{b_1 + b_2 + b_3}{3}$$

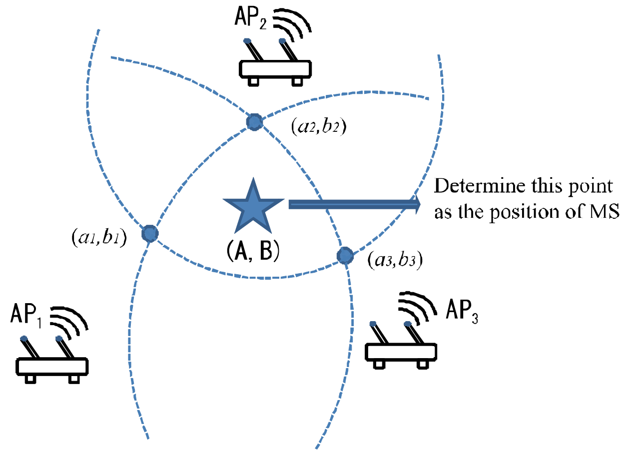

Fig. 2. Positioning in practice by the conventional method

The conventional method estimate the position of the MS using all the APs detected by the MS. However, with the irregular movement of the MS, the signal will attenuate severely caused by long distances and obstacles between the MS and APs. We noticed that the positioning can be made with the estimated distances from three APs. Thus, we proposed a method named as adaptable APs method to select three APs from whose received signal strengths are greatest [9].

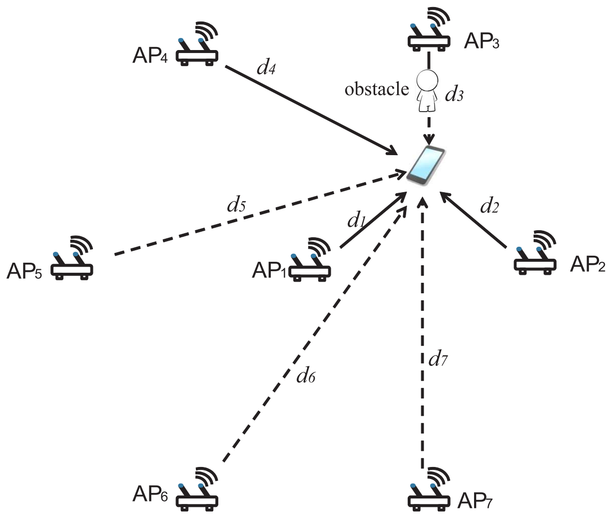

Fig. 3. Estimate the position of the MS in indoors environment

For instance, there are seven Aps (AP_1, AP_2... AP_7) and one MS in a indoor environment, as shown in Fig.3. The signals attenuate severely caused by long distances between the MS and AP_5, AP_6 and AP_7. Moreover, the human between the MS and AP_3 also cause severely attenuation. In this condition, the adaptable APs method is to select AP_1, AP_2 and AP_4 which have the greatest received signal strengths to estimate the position of the MS.

III. Proposed Methods

A. Proposed frequency-average (FA) method

Radio propagation in indoor environments suffer from multipath effect caused by reflection and refraction from numerous objects. The effects of multipath include constructive and destructive interference, and phase shifting of the signal. The magnitudes of the signals arriving by the various paths have a distribution known as the Rayleigh distribution. The received signal strength changing rapidly, therefore it is difficult to determine α in time domain [10].

To estimate α ccurately, we propose a novel estimation algorithm utilizing the average of pilot signal strength in frequency domain. In frequency domain, frequency selective fading is generated caused by multipath. The power of each sub-carriers is quite different due to the multipath fading. However, if we neglect the attenuation in the propagation, the averaged received power would approach to the transmitted power since

$$E[h_k] \simeq 1 \qquad (5)$$

where h_k means the channel response of the kth sub-carrier and $E[h]$ denotes the ensemble average operation.

We assume $E[hk] = 1$, then we have

$$\bar{P}_r = \alpha \bar{P}_r + N' \qquad (6)$$

where

$$\bar{P}_t = \frac{\sum_{k=1}^{N_c} p_t(k)}{N_c}, \qquad (5)$$
$$\bar{P}_r = \frac{\sum_{k=1}^{N_c} p_r(k)}{N_c},$$

where $p_t(k)$ and $p_r(k)$ are the transmitted and received pilot signal strength and N_c is the number of sub-carriers. $\bar{P}_t$ is a known parameter and $\bar{P}_r$ can be calculated at the receiving node. Therefore, we can estimate α then determine d accurately to compare with the conventional RSS-based method.

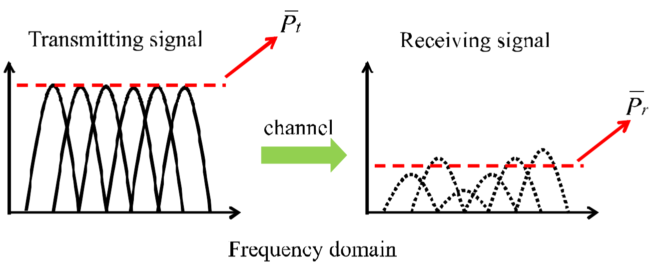

Fig. 4. Frequency selective fading

B. Proposed weighted least-squares method

The conventional location estimation method is a straightforward approach, which compute the center of the intersection points of the circles with radius of estimated distances to identify the location of the MS. The location of the MS also can be identified by minimizing the sum of squares of a cost function, i.e., least-squares algorithm [11], which do not lead to a significant performance improvement. However, since signals received from different APs have different propagation distances, mutipath fading, and noises, the estimation of the location of MS based on the reliability of the signals received from APs is considered to be a reasonable scheme. Therefore, we propose a novel method to identify the location of the MS with considering the reliability of the received signals and minimizing the sum of squares of a nonlinear cost function, i.e., weighted least-squares algorithm.

The reliability of the received signal ω can be considered as the ratio of the desired signal power to the estimated power error.

From Eqs. (1) and (3), the definition of the received signal power as

$$P_r' = HG_tG_r\left(\frac{\lambda}{4\pi d}\right)^2 P_t + N \qquad (8)$$

and the estimated power error is defined as

$$\varepsilon = |P_r' - P_r| \qquad (9)$$

The estimate power error is in proportion to the received signal power. Thus we define the reliability of the signal ω as

$$\omega = \frac{P_r}{\varepsilon} = \frac{P_r}{|P_r' - P_r|} \qquad (10)$$
$$= \frac{P_r}{|(H-1)G_tG_r(\frac{\lambda}{4\pi d})^2 P_t + N|}$$
$$= \frac{1}{|(H-1) + \frac{N}{P_r}|}$$

If the ensemble average of the channel $E[h_k] = 1$, the above equation can be rewritten as

$$\omega \simeq \frac{1}{|(1-1) + \frac{N}{P_r}|} = \left|\frac{P_r}{N}\right|$$

We assume that the MS, located at (x_{MS},y_{MS}), the N APs located at (a_1,b_1), (a_2,b_2), ..., (a_N,b_N), the estimated distances are D_1, D_2, ..., D_N. As a performance measure, the cost function can be formed by

$$F(x) = \sum_{i=1}^{N} \omega_i \vartriangle d_i^2$$

where ω_i is the reliability of the signal from the AP_i, and $\vartriangle d_i$ is given as

$$\vartriangle d_i = \sqrt{(x_{ms} - a_i)^2 + (y_{ms} - b_i)^2} - D_i$$

Assume that the N_i of signal from AP_i can be characterized by the normal distribution with the same deviation. We can obtain the following condition as

$$\omega_1 : \omega_2 : \ldots : \omega_n \propto P_{r1} : P_{r2} : \ldots : P_{rn}$$

In this case, the reliability of the signal ω_i from AP_i, can be replace with the received signal power P_r. From this reason, the proposed method can identify the accurate position of the MS compare with the conventional method.

IV. Simulation Results

Simulations have been conducted to evaluate the performance of the proposed methods. Suppose that an OFDM system with 62 subcarriers which have a frequency of 2.4GHz. Table I shows the simulation parameters. Considering the complexity of calculation and analysis, we set one AP to the center and six APs to the vertices of a regular hexagon of side length 400m, respectively. Suppose *d* is distance between the MS and the center of the hexagon. The simulation model is set as shown in Fig. 5.

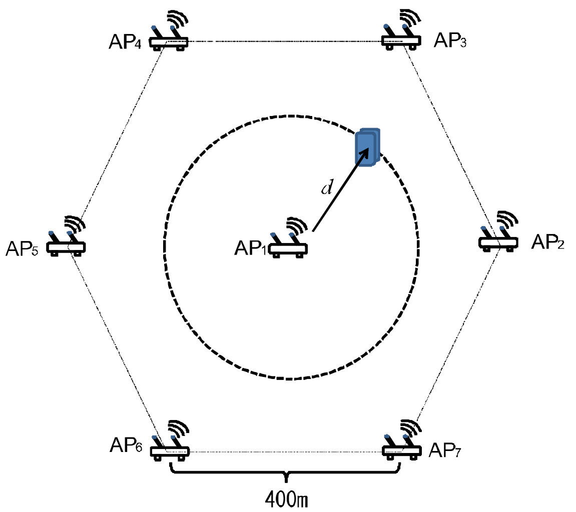

Fig. 5. Simulation model

We assumed that the MS move from the center of hexagon (the position of AP_1) outward with the distance *d* from the center. We estimate the location of the MS utilizing the conventional method which use all the APs, and the adaptable APs method which use the three APs with greatest signal strengths, respectively. Then we have the simulation results as shown in Fig. 6 and 7.

TABLE I. Simulation parameters

Transmitting signal strength	15dBm
Gaussian white noise strength	-90dBm
FFT size	64
Guide interval	16
Modulation mode	QPSK
Carrier frequency	2.4GHz
Pilot number	4
Channel model	Rayleigh fading
Multipath number	5
Attenuation model	Friis
Doppler frequency	10 Hz

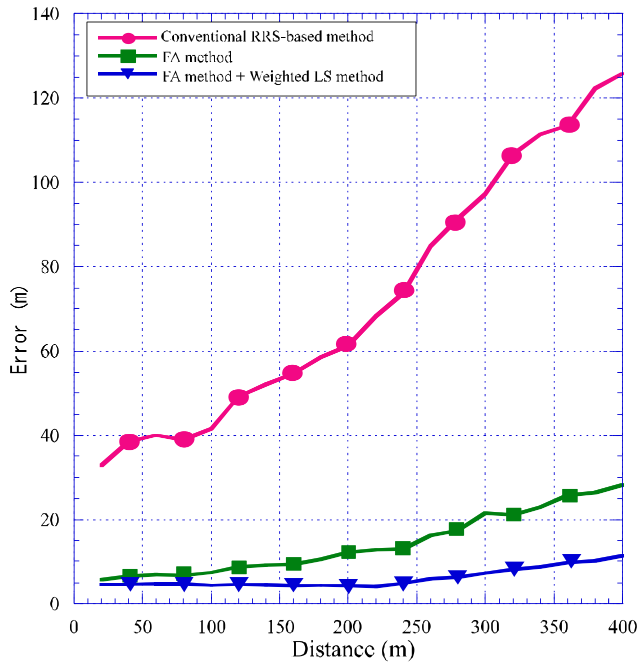

Fig. 6. The simulation result with 7 APs

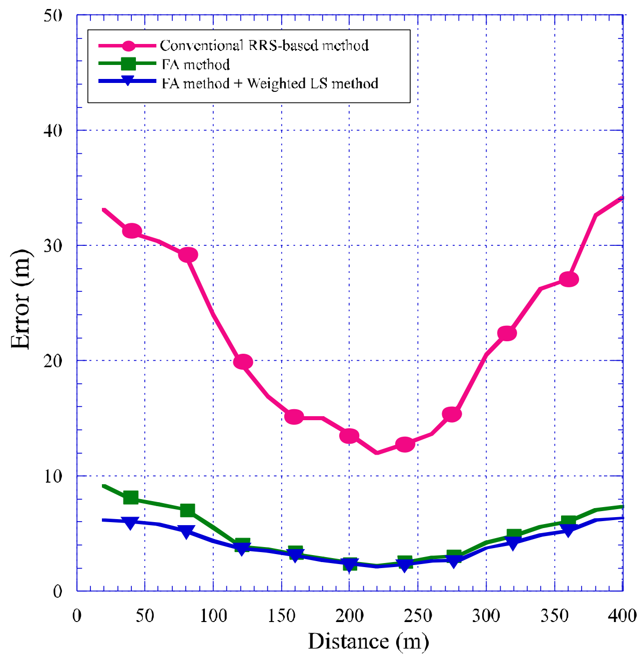

Fig. 7. The simulation result with adaptable 3 APs

The conventional method utilizing the ratio of the mean signal strength and all of the APs , which results in large errors; The proposed frequency-average method which estimated the distance between APs and the MS accurately, improved the accuracy significantly; Combined with the weighted least-squares method, the mean location error is reduced under 12m with 7 APs as shown in Fig. 6, and reduced under 7m with adaptable 3 APs as shown in Fig. 7. Considering the results, the proposed methods has better performance than the conventional method.

V. Conclusion

A conclusion section is not required. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions. In this paper, we proposed two novel methods to determine the location of the MS more accurately in WLAN based systems.

FA method based on RSSI is proposed to estimate the distance between APs and the MS using the average of pilot signal strengths in frequency domain. When determine the position of the MS by its estimated distances from multiple APs, weighted LS method is proposed to determine the location more accurately. The simulation results show that the proposed methods can achieve better accurate estimation property than that of the conventional methods. The future work will be focus on implementing an experiment in an indoor environment for improving algorithm.

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