Position Estimation of Wireless Access Point Using Directional Antennas

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Abstract. In recent years, wireless LAN technologies have experienced unprecedented growth, and new services and problems have occurred. In this paper, we propose a position estimation technique using directional antennas to assist the detection of wireless access points. Using an asymmetric model for estimation, our technique can radicalize probability distribution quicker than using a symmetric model. Our technique consists of three steps. The first measures the current position of the user, the direction of the antenna and the received signal strength of a target wireless access point. The second step estimates the position of the wireless access point from measured data using a signal strength model based on directivity. And the final step presents estimated results that assist the user. These steps are repeated for real-time assistance. We also conducted an evaluation experiments to clarify the effectiveness of our proposed technique.

1 Introduction

In recent years, wireless LAN technologies are widely being used and several devices are equipped with wireless LAN communication capabilities: for example, laptop PCs, PDAs, mobile phones[18], printers, and digital cameras. With the spread of wireless LAN technologies, new services and problems have come to light. For example, positioning systems and location-aware services using wireless LAN technologies have been proposed[1, 17, 5, 9, 2, 8]. Some problems, however, are the unauthorized deployment of wireless access points and use of wireless access points without proper security configuration [11], which cause intrusions into networks, communication failure of wireless LANs, and interceptions of ID or password for web site authentication by the access points spoofing.

The need for positioning access points arises on several scenes. For example, some positioning systems based on wireless LAN use access point positions at positioning, therefore, the collection and registration of the positions of access points are needed during the construction[6]. Additionally, when unauthorized wireless access points cause communication failure or security problem, they must be detected and removed. The aim of our research is to realize assistance for searching for wireless access points.

T. Strang and C. Linnhoff-Popien (Eds.): LoCA 2005, LNCS 3479, pp. 144–156, 2005.

Although a number of studies have been made on user's positioning using positions of wireless access points and received signal strength in recent years[1, 7, 4], few studies have been made on positioning of wireless access points using user's position and received signal strength. In this paper, we propose a position estimation technique of wireless access points using user's position, the received signal strength from them, and a direction of the directional antenna the user equips. Our technique uses a pre-observed signal strength model as learning data for estimation.

One characteristic of our technique is using directional antennas, that is, using an asymmetric model for estimation. Therefore, our technique can radicalize probability distribution quicker than by using a symmetric model. Because we use directional antennas, antenna direction affects the received signal strength in addition to the distance between the sender and the receiver. Therefore, we can get useful information from the change of antenna direction. Although our technique uses direction information, our technique differs from triangulation. Triangulation needs measurements at multiple positions for estimation and restricts measurements style, that is, needs rotation for measurements at the position. On the other hand, our technique can estimate a position using the data measured at only one position and set measurements style free.

2 Related Work

Wardriving is defined as driving around looking for wireless networks [14]. An user drives around with a laptop PC or a PDA in the user's vehicle for detecting wireless networks. Some users log and collect the position of the networks they found using GPS. The aim of wardriving is detecting wireless networks, that is, detecting the area in that wireless access is available. Although a lot of softwares for wardriving exist, almost of them present only received signal strength data as information for detecting wireless access points [15, 16]. On the other hand, the concern of our research is positioning wireless access points. Therefore, advanced assistance is needed for it. Our technique can estimate the position of a wireless access point, and visualize the results for assistance.

Wireless Security Auditor is an IBM research prototype of an 802.11 wireless LAN security auditor running on PDA[12]. This tool detects wireless access points, and lists the security configuration information of them. Netwrok administrators can use it for managing their networks. However, it is insufficient to solve the network problems by unauthorized wireless access points whose positions are unknown. This tool also presents only received signal strength data as information for detecting wireless access points like most wardriving tools.

3 Proposal Method

Our technique consists of the following three steps. The first step measures the current position of the user, the directional antenna direction, and the received signal strength from a target wireless access point. The second step estimates an access point's position using observed data and a signal strength model based on directivity. The final step presents the estimated results to the user to assist access point detection. These three steps are repeated for real-time assistance.

3.1 Signal Strength Model Based on Directivity

Our technique uses a signal strength model as pre-observed learning data for estimation. Some models proposed so far are based on only the distance between a sender and a receiver[3]. In addition, our technique uses the direction of a receiver's antenna. That is, our technique uses an asymmetric model for estimation.

In our technique, the signal strength model is defined as the function with the relative position of an access point and an antenna as input patrameters. This function outputs probability density function(*pdf*).

The relative position of access points and antennas is composed of distance l between them and angle a between the reference direction of the antenna and the direction to the access point from the antenna. The *pdf* of the received signal strength follows from the signal strength model and the relative position.

$$pdf_{l,a} = SignalModel(l, a) \tag{1}$$

This model is constructed by measuring received signal strength on a known relative position. The *pdf* is calculated from measured data.

3.2 Position Estimation

In this section, we show the details of our estimation technique. We use posterior probability according to Bayesian inference for estimation. This calculation has a good property for processing data measured repeatedly.

First, we define measured data and the candidate position for estimation. Set O is defined by the set of observation o_i measured repeatedly. Each observation consists of three elements: the user's current position p_i, the direction d_i of the antenna the user equips, and the received signal strength s_i of a target wireless access point.

$$O = \{o_1, o_2, \ldots, o_m\} \tag{2}$$

$$o_i = (p_i, d_i, s_i) \quad i = 1, 2, \ldots, m \tag{3}$$

'Candidate position' is defined as the position of a target that estimates whether a wireless access point exists. Set C is defined by a set of candidate position c. We assume that a target wireless access point exists somewhere in C.

$$C = \{c_1, c_2, \ldots, c_n\} \tag{4}$$

We calculate the posterior probability of each candidate position $P(c_j \mid o_1, \ldots, o_m)$ using observation set O and a signal strength model as the existence probability of a target wireless access point at each candidate position. The caluculation follows.

First, we get the $P(s_i \mid p_i, d_i, c_j)$ of each candidate position c_j and each observation o_i using the signal strength model. Consider a certain observation o_i and a certain candidate position c_j. We calculate the relative position of (l, a) using p_i and d_i as elements of observation o_i and c_j, and get $pdf_{l,a}$ from the signal strength model and (l, a). The $pdf_{l,a}$ and s_i as an element of observation o_i give the posterior probability of s_i, that is, $P(s_i \mid p_i, d_i, c_j)$.

Next, we calculate $P(c_j \mid o_1, \ldots, o_m)$ using the $P(s_i \mid p_i, d_i, c_j)$ of each candidate position and observations. Assuming that the prior probability of each candidate position is even and that each observation is independent, $P(c_j \mid o_1, \ldots, o_m)$ is calculated by $P(s_i \mid p_i, d_i, c_j)$ for each candidate position and observation. Posterior probability $P(o_i \mid c_j)$ is represented as follows using posterior probability $P(s_i \mid p_i, d_i, c_j)$.

$$
\begin{aligned}
&P(o_i \mid c_j) \\
&= P(p_i, d_i, s_i \mid c_j) \\
&= \frac{P(p_i, d_i, s_i, c_j)}{P(c_j)} \\
&= \frac{P(s_i \mid p_i, d_i, c_j) \cdot P(p_i, d_i, c_j)}{P(c_j)} \\
&= P(s_i \mid p_i, d_i, c_j) \cdot P(p_i, d_i) \\
&\qquad (because\ c_j\ is\ independent\ of\ p_i, d_i)
\end{aligned} \tag{5}
$$

Bayesian inference gives the posterior probability of each candidate position as follows.

$$
\begin{aligned}
&P(c_j \mid o_1, \ldots, o_m) \\
&= \frac{P(o_1, \ldots, o_m \mid c_j) \cdot P(c_j)}{\sum_{l=1}^{n} P(o_1, \ldots, o_m \mid c_l) \cdot P(c_l)}
\end{aligned} \tag{6}
$$

Given that each observation o is independent, the posterior probability of observation set $o_1, \ldots, o_m$ is as follows.

$$
\begin{aligned}
P(o_1, \ldots, o_m \mid c_j) &= \frac{P(o_1, \ldots, o_m, c_j)}{P(c_j)} \\
&= \frac{\prod_{k=1}^{m} P(o_k, c_j)}{P(c_j)}
\end{aligned} \tag{7}
$$

Given that the prior probability of each candidate position $P(c_j)$ is even, the posterior probability of each candidate position is determined as follows by expressions 5,6 and 7.

$$
\begin{aligned}
&P(c_j \mid o_1, \ldots, o_m) \\
&= \frac{\prod_{k=1}^{m} P(o_k \mid c_j)}{\sum_{l=1}^{n} \left\{ \prod_{k=1}^{m} P(o_k \mid c_l) \right\}} \\
&= \frac{\prod_{k=1}^{m} P(s_k \mid p_k, d_k, c_j)}{\sum_{l=1}^{n} \left\{ \prod_{k=1}^{m} P(s_k \mid p_k, d_k, c_l) \right\}}
\end{aligned} \tag{8}
$$

Finally, we use the posterior probability of each candidate position as the existence probability of a wireless access point at each candidate position.

This calculation can be done incrementally by buffering $\prod_{k=1}^{m} P(s_k \mid p_k, d_k, c_j)$ of each candidate position. Therefore the computation time and the memory size for the calculation are constant despite the number of observation. This property is better suited for processing data measured repeatedly.

4 Wireless Search Assistant

A lot of devices are needed for using our technique. It is hard for an user to search for wireless access points on carrying the devices by the hand. Therefore, we developed an assistant system based on our technique, named Wireless Search Assistant. All required devices are packaged within this system.

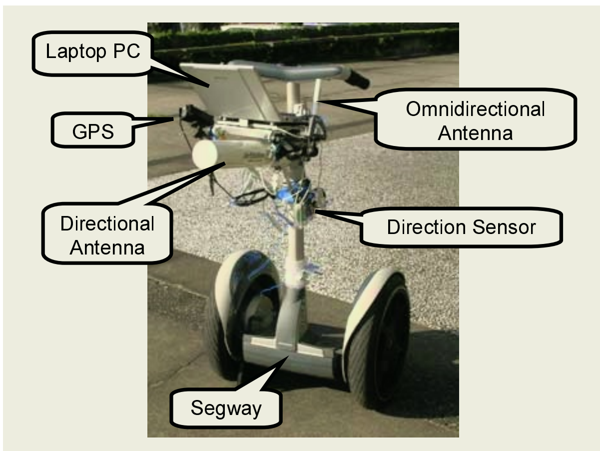

Fig. 1. Wireless Search Assistant Overview

Figure 1 shows an overview of this system, which is composed of a directional antenna, a GPS terminal, four fiber sensors, a direction sensor, a laptop PC, a Head Mount Display(HMD), a Segway[13], and our estimation software. This system measures antenna direction and received signal strength by using direction sensors and directional antennas. In an outdoor environment, this assistant's position is measured by GPS. In an indoor environment, it is measured by dead reckoning using fiber sensors. Because these devices are equipped on a Segway, it has outstanding mobility both indoors and outdoors. Therefore this system is very useful for detecting a wireless access point.

Users searches by looking at estimated results displayed on laptop PCs and HMDs. Our estimation software's GUI consists of the map and signal windows and the access point list(Figure 2). The map window presents the user's position, the antenna direction, and the estimated results that overlap the map. Users

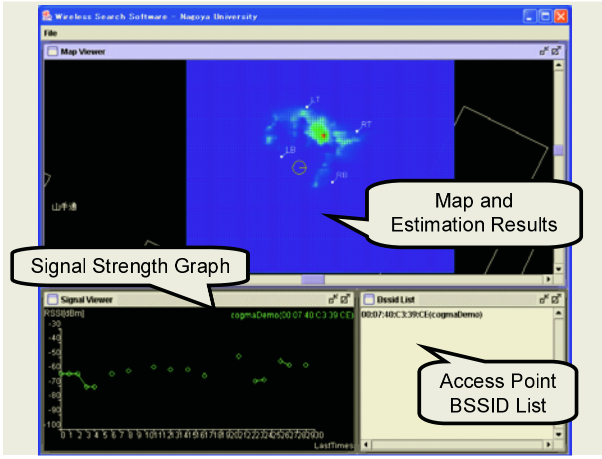

Fig. 2. Estimation Software Screenshot

select a target wireless access point from an access point list and a signal strength model for estimation. This system repeatedly measures data, estimates position, and presents the estimated results on a map, which are represented by colors.

5 Evaluation Experiment

In this section, we evaluate estimation accuracy and search time of our technique. We conducted two cases in each experiment: using a directional antenna and an omnidirectional antenna. 'Directional case' is defined by using a directional antenna, and 'omnidirectional case' is defined by using an omnidirectional antenna. We compared these cases and discussed the results. The Wireless Search Assistant described above was used for this experiment.

5.1 Experiment Environment, Hardware and Setting

Figure 3 shows an overview of the experiment environment conducted in the open air; the user's position was measured by GPS. 16 boxes ware set on a 4 × 4 coordinate grid at 7 meters intervals. Contents of the boxes couldn't be confirmed from outside.

The devices used in the experiment are listed below and Table 1 shows device specification.

- Directional antenna (Buffalo Technology, WLE-HG-DYG)
- Omnidirectional antenna (Buffalo Technology, WLE-NDR)
- GPS terminal (Garmin International Inc., eTrex Vista-J)
- Direction sensor (MicroStrain Inc., 3DM)
- Wireless access point (Buffalo Technology, WHR2-G54)

Fig. 3. Experiment Environment Overview

Table 1. Device Specification

Directional antenna (WLE-HG-DYG)	Polarization Method	Vertical polarity wave
	Directivity, Vertical	$32 \pm 5°$ Half value angle
	Directivity, Horizontal	$32 \pm 5°$ Half value angle
	Antenna Gain	absolute gain 14 dbi
	Frequency Range	2401-2484 MHz (1-11ch)
Omnidirectional antenna (WLE-NDR)	Polarization Method	Vertical polarity wave
	Antenna Gain	absolute gain 2.5 dbi
	Frequency Range	2401-2484 MHz (1-11ch)
GPS terminal (eTrex Vista-J)	Accuracy	<15 meters, 95% typical
Direction sensor (3DM)	Range	Yaw: ± 180 degrees
	Accuracy	Yaw: ± 1.0 degrees typical

In each experiment we used the same wireless access point in the construction of a signal strength model. The communication standard used in this experiment was only IEEE 802.11b. We used a digital map (Spatial Data Framework) published by the Geographical Survey Institute[19] for presentation. Estimation setting is the candidate position set C of the lattice position points on the coordinate grid(100×100 meters) at 1 meter intervals that covers sufficient experiment space. Measurement intervals are one second.

5.2 Construction of Signal Strength Model

Before the experiment, we constructed signal strength models of directional and omnidirectional antennas. We assumed that a wireless access point is omnidirectional that can be measured without obstacles.

During construction, we assumed that the probability density function of the received signal strength was a normal distribution function and calculated expectation and variance from the measured data using a maximum-likelihood method. In this experiment, we supposed that the interpolation of the probability density function is the interpolation of the parameters by inverse distance weighting(IDW). In particular, given that the interpolation point is p, the sampling points are $q_1 \ldots, q_n$, their respective values are $v_1, \ldots, v_n$, and the distances from p to the sampling points are $l_1, \ldots, l_n$, the value of p, v_p is interpolated using the follow expression. In this experiment, we supposed that inverse distance weighting power w is 1.

$$v_p = \frac{\sum_{i=1}^{n} \frac{v_i}{l_i^w}}{\sum_{i=1}^{n} \frac{1}{l_i^w}} \tag{9}$$

In the directional case, we measured the received signal strength when distance l was 1, 2, 4, 6, 8, 12, 16, 32, 64, and 128 meters and the angle a was 0, 22.5, 45, 67.5, 90, 112.5, 135, 157.5, and 180 degrees. In the omnidirectional case, we measured the received signal strength when the distance l was 1, 2, 4, 6, 8, 12, 16, 32, 64, and 128 meters, assuming that the received signal strength of the omnidirectional antenna is ideal, that is, that antenna direction is independent of received signal strength. Unlike the experiments, the measurements of each case were performed 300 times in 30 seconds at measurement intervals of 0.1 seconds. Figure 4 shows the directional pattern of the used directional antenna at a distance of 16 meters by the measurement.

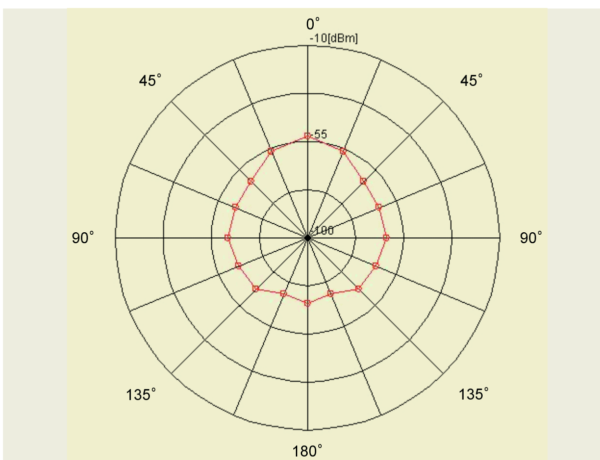

Fig. 4. Directional Pattern of Directional Antenna (16 meters)

5.3 Estimation Accuracy Experiments

We experimented for estimation accuracy with directional and omnidirectional antennas. Here, we supposed that estimation accuracy measurement is the distance between the actual position of a target wireless access point and a position with the highest probability of all candidate positions, wihich is called an 'estimated position'. 'Error distance' is defined as this distance. That is to say, the shorter the error distance is, the higher the estimation accuracy is.

We investigated time transition of error distance. We hid a wireless access point in one of 16 boxes and gave three subjects one minute to search for it. In this experiment, two modes of presentation were conducted. The first mode (called 'half mode') presented only signal changes without estimated results, presenting signal window and access point list (bottom left and bottom right of Fig. 2). The second mode (called 'full mode') presented estimated results in addition to half mode using map window (top of Fig. 2).

Figure 5 and 6 show all results in full and half modes. The vertical axis is error distance and the horizontal axis is time.

At each mode, in each case, error distance shortens as measured data increases. Compared to the omnidirectional case and looking overall at each mode, error distance shortens quicker in the directional case. In the omnidirectional case, half mode error distance shortens quicker than the full mode. The measured data in the experiment show the users' movements between full and half modes. In full mode, users tend to come close to the estimated position presented on a map. On the other hand, in half mode, users tend to move more widely in experiment space than in full mode. It seems reasonable to suppose that this

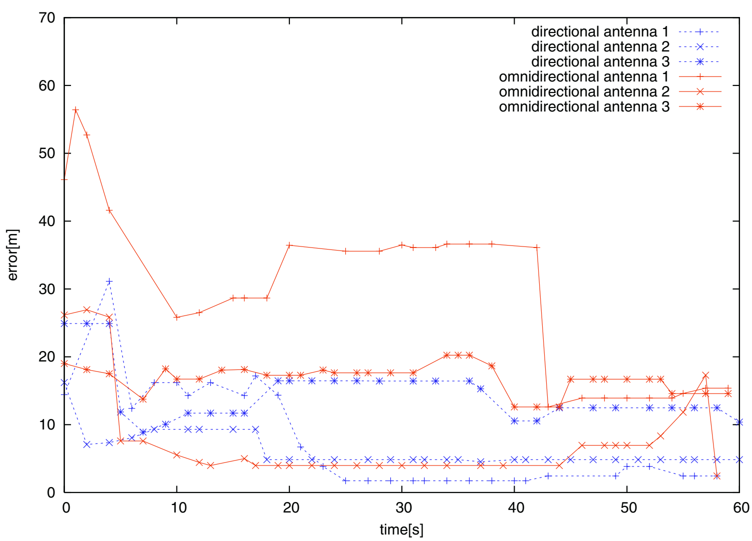

Fig. 5. Time Transition of Estimation Accuracy in Full Mode

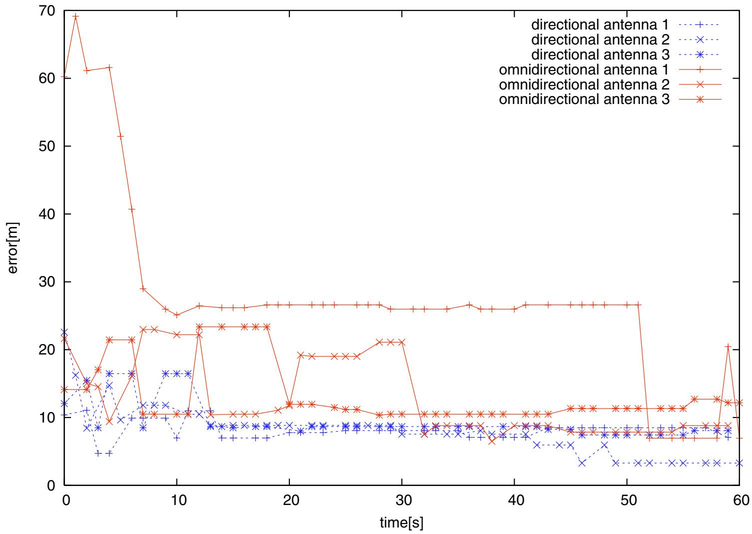

Fig. 6. Time Transition of Estimation Accuracy in Half Mode

difference causes that error distance at half mode shortens eariler than at full mode; users' movements have a effect on estimates, in particular in omnidirectional case.

Differences in the error distance results in the same conditions likey arise because there are no fixed starting search positions.

Perhaps error distance differences between the directional and omnidirectional cases arise because the signal model of the omnidirectional antenna is insufficient, in addition to the effects of our technique. Although we assume that an omnidirectional antenna is truly omnidirectional, perhaps the antenna is only slightly directional amid obstacles.

5.4 Search Time Experiments

Next, we experimented for the search time with directional and omnidirectional antenna. 'Search time' is defined as the time required from starting a search to selecting a box in which a target wireless access point seems to exist.

We investigated search time and whether the selection was correct. We hid a wireless access point in one of the 16 boxes for which three subjects searched. The presentation mode of the Wireless Search Assistant was full.

Tables 2 and 3 show results in directional and omidirectional cases. Compared to omnidirectional cases, search time is about half as long as in directional cases. It seems reasonable to suppose that search time is shortened by effective direction information. The selections were all correct in the directional case, although they are all incorrect in the omnidirectional case.

All trajectories of subject 1 in the directional and omnidirectional cases are shown in Figures 7 and 8. The box is described as square with numbering and

Table 2. Directional Case Results

subject's ID	search time(seconds)	correct or incorrect
1	30	correct
2	33	correct
3	36	correct

Table 3. Omnidirectional Case Results

subject's ID	search time(seconds)	correct or incorrect
1	52	incorrect
2	66	incorrect
3	96	incorrect

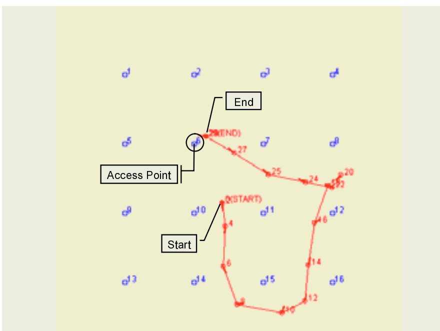

Fig. 7. Trajectory(Subject 1, Directional)

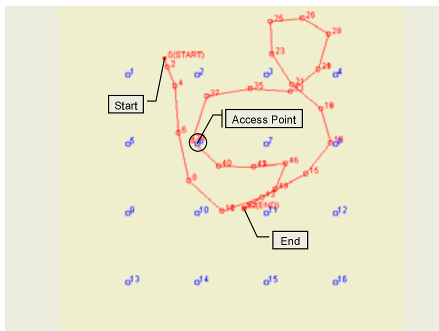

Fig. 8. Trajectory(Subject 1, Omnidirectional)

the subject's position is as circle. In the directional case, the antenna direction is also described. The wireless access point existed in the 6^{th} box. Subject 1 selected correctly in the directional case, although he incorrectly selected the 2^{th} box in omnidirectional case. We suggest that subject 1 moved near the wireless access point in the directional case because the estimated results converged with fine accuracy. On the other hand, subject 1 moved in the space widely in the omnidirectional case because the estimated results did not converge with a high enough percentage of fine accuracy.

It seems reasonable to suppose that search time is shortened by effective direction information.

6 Conclusions and Future Work

In this paper, we proposed a position estimation technique of a wireless access point for assistance in detection. Our technique is based on directional antennas.

Using an asymmetric model for estimation, our technique can radicalize probability distribution quicker than using a symmetric model. Our technique consists of the following three steps. The first step measures the current position of an user, the antenna direction, and the received signal strength of a target wireless access point. The second step estimates the position of the wireless access point from measured data using a pre-observed signal strength model based on directivity. And the final step presents estimated results to assist the user. These steps are repeated for real-time assistance. We conducted experiments with our technique and clarified its effectiveness.

Future work includes an estimation of wireless access point position on the other floors. We intend to use a 3-dimentional signal model for solving the problem. We also plan to consider estimations using an indoor map for more assistance. In an indoor environment, however, a lot of problems for estimation are remained, such as, reflection, diffraction and multipath.

References

1. Paramvir Bahl and Venkata N. Padmanabhan, RADAR:An In-Building RF-based User Location and Tracking System, in Proc. of IEEE Infocom, Tel Aviv, Isreal, 2000.
2. Teruaki Kitasuka, Tsuneo Nakanishi, and Akira Fukuda, Wireless LAN based Indoor Positioning System WiPS and Its Simulation, 2003 IEEE Pacific Rim Conference on Communications, Computers and Signal Processing (PACRIM'03), pp. 272-275, August 2003.
3. Aleksandar Neskovic, Natasa Neskovic and George Paunovic, Modern Approaches in Modeling of Mobile Radio Systems Propagation Environment, IEEE Communications Surveys, Third Quarter 2000.
4. Bill Schilit, Anthony LaMarca, Gaetano Borriello, William Griswold, David McDonald, Edward Lazowska, Anand Balachandran, Jason Hong and Vaughn Iverson, Challenge: Ubiquitous Location-Aware Computing and the Place Lab Initiative, In Proc. of WMASH 2003, San Diego, CA. September 2003.
5. Jason Hong, Gaetano Borriello, James Landay, David McDonald, Bill Schilit and Doug Tygar, Privacy and Security in the Location-enhanced World Wide Web, In Proc. UbiComp 2003, Seattle, WA. October 2003.
6. Bill Schilit, Anthony LaMarca, David McDonald, Jason Tabert, Eithon Cadag, Gaetano Borriello, and William G. Griswold, Bootstrapping the Location-enhanced World Wide Web, In Proc. UbiComp 2003, Seattle, WA. October 2003.
7. Paramvir Bahl, Anand Balachandran, Allen K.L. Miu, W.Russell, Geoffrey M. Voelker and Yi-Min Wang, PAWNs: Satisfying the Need for Ubiquitous Connectivity and Location Services, IEEE Personal Communications Magazine (PCS), Vol. 9, No. 1, February 2002.
8. Jeffrey Hightower and Gaetano Borriello, Location Systems for Ubiquitous Computing, Computer, Vol. 34, No. 8, pp.57-66, IEEE Computer Society Press, Aug. 2001.
9. Cheverst K., Davies N., Mitchell K. and Friday A., Experiences of Developing and Deploying a Context-Aware Tourist Guide: The GUIDE Project, Proc. of MOBICOM 2000, pp.20-31, Boston, ACM Press, August 2000.

10. Rashmi Bajaj, Samantha Lalinda Ranaweera and Dhara P. Agrawal, GPS:Location-Tracking Technology, IEEE Computer, Vol 35, No.4, pp.92-94, 2002.
11. Guideline for wireless LAN security, Japan Electronics and Information Technology Industries Association, http://it.jeita.or.jp/perinfo/committee/pc/wirelessLAN2/index.html (Japanese)
12. Wireless Security Auditor, Global Security Analysis Lab, IBM Research, http://www.research.ibm.com/gsal/wsa/
13. Segway, http://www.segway.com/
14. wardriving.com, http://www.wardriving.com/
15. NetStumbler, http://www.netstumbler.com/
16. Kismet, http://www.kismetwireless.net/
17. WiFi positioning system, Hitachi AirLocation(TM), http://www.hitachi.com/
18. N900iL, http://www.nttdocomo.co.jp/
19. Geographical Survey Institute, http://www.gsi.go.jp/