ORIENTATION ESTIMATION METHOD USING DIVERGENCE OF SIGNAL STRENGTH DISTRIBUTION

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ABSTRACT

Over the last few years, many positioning systems using wireless LAN have been developed. Some systems use signal strength for positioning. But the distribution of received signal strength depends on orientation of mobile terminal. In this paper, we examine the differences of received signal strength distribution to each orientation and propose an orientation estimation method using the divergence of received signal strength distribution. With our method, users can determine orientation only using a wireless LAN adapter. Evaluation results show that the accuracy of 2-way estimation is 92% and 4-way estimation is 83% under six seconds observation of four access points.

INTRODUCTION

In recent years, many places, ranging from universities, companies, and homes to railway stations, airports, amusement facilities, and shopping malls have introduced wireless LAN and established wireless LAN facilities. Therefore, in the future we expect wireless LAN to become available anytime and anywhere. In addition, a considerable number of studies have been made on positioning systems using wireless LAN: [1][2][3][4][5][6][7][8][9]. Some existing systems use received signal strength information for positioning. But, received signal strength is empirically known to vary according to the relative position between terminals and access points. Since differences of received signal strength at the same location affects positioning accuracy, it is important to examine such distribution differences to each orientation. In this paper, we examine the difference of received signal strength to each orientation and propose an orientation estimation method that uses divergence of received signal strength distribution. Our method estimates orientation to define divergence among received signal strength distribution and uses the information of the divergence of multiple access points. We implemented this orientation estimation system and conducted evaluation experiments on our campus and confirmed our method's effectiveness. This paper is presented in four parts. First, we survey how received signal strength varies by each orientation and describe our orientation estimation technique. Third, we explain our experimental setup and details. Then, we present the results of each experiment. Finally, we introduce related work and present conclusions.

DIFFERENCE OF SIGNAL STRENGTH

In this section, we examine the differences of the received signal strength distribution for each orientation. Some wireless LAN based positioning systems use the received signal strength information for their estimation. But, it is empirically known that received signal strength varies according to the relative angles between terminals and access points. For the survey, we observed received signal strength distributions for each orientation at identical positions.

Figure 1 shows an outline of the observations. To avoid the effects of multipath, interference, fading, and any other possible interruptions, we performed these observations outdoors in good weather and collected received signal strength distribution for two minutes to 8-way orientation ($45°$ relative each) at a position 10 m from the access point. To survey human effects on received signal strength distribution, we conducted two types of observations. First, received signal strength is observed when a person is holding the terminal in his hand. Secondly, we placed the terminal on a round table and observed received signal strength. In addition, we used three kinds of wireless LAN cards to investigate the differences of received signal strength distribution among them.

Figure 2 shows the average value of received signal strength for each orientation with humans. In Fig. 2, the distance from the middle of a circle shows the average received signal strength, and each axis shows the relative angle between the terminal and the access point. From Fig. 2, we obviously see the difference of received signal strength for each orientation. For example, in wireless LAN card A, the terminal observed the highest average at relative angle $0°$ when the user is facing the access point. Even in the same location, received strength signal varies according to the wireless LAN card.

Figure 3 shows observation results without human. Fig. 3 and Fig. 2, which is the distance from the middle of the circle, show average received signal strength, and each axis shows the relative angle between the terminal and the access point. Fig. 3 (observed without human) shows a slight difference of received signal strength in comparison with Fig. 2 (observed

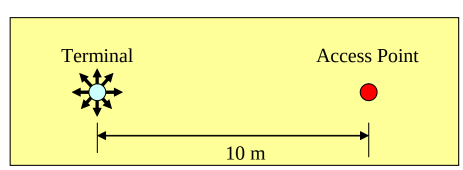

Fig. 1. *Observation of 8-way received signal strength*

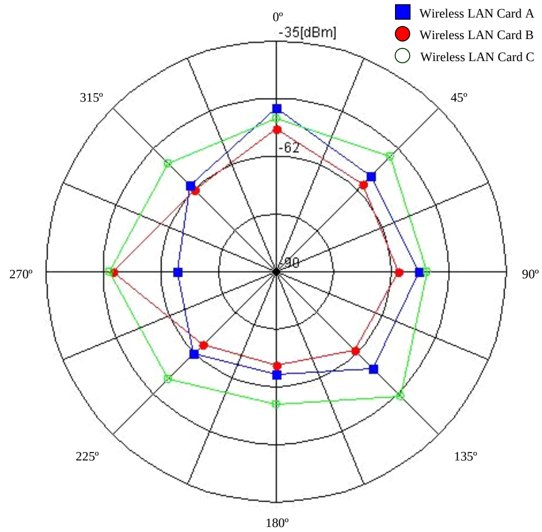

Fig. 2. *Average received signal strength for each orientation (With human)*

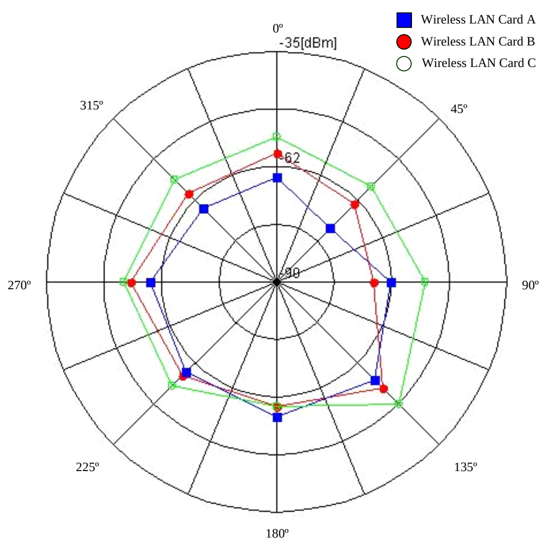

Fig. 3. *Average received signal strength for each orientation (Without human)*

with human). However, we can see differences of received signal strength in a particular orientation. To take a simple example, in wireless card A, the terminal observed an average -71 dBm at relative angle $45°$, which is 10 dBm lower than the total wireless card A average. Another example is wireless LAN card C, where the terminal observed an average of -48 dBm at relative angle $135°$, which is 8 dBm higher than the total average of wireless card C. One cause for these differences may reflect the attached place of the wireless LAN cards (for example, wireless LAN cards for PCMCIA slots or built-in wireless LAN cards) and the shape of terminal. These influences cause different received signal strengths for each orientation and generate directional characteristics.

For more details, Fig. 4 shows the received signal strength distribution for each orientation in the observations. There are six figures in Fig. 4. The three figures on the left show the observation results for three kinds of wireless LAN cards with human. The three figures on the right show observation results without human. The horizontal axis shows the value of the received signal strength, and the vertical axis shows the probability density in a particular orientation. Each line shows received signal strength distribution.

The top two figures of Fig. 4 show the wireless LAN card A results. In comparison with the top right figure (wireless LAN card A, without human) at relative angle $180°$, the top left figure (wireless LAN card A, with human) shows low received signal strength distribution. The user was standing between the terminal and the access point, which caused the obstruction and these differences. One further difference must not be ignored: despite the same location, received signal strength varies from around -70 to -50 dBm.

The middle of Fig. 4 shows the results of wireless LAN card B. The terminal observed received signal strength around -60 dBm at relative angle $180°$ in the middle of the right figure (wireless LAN card B, without human). But the terminal observed received signal strength around -68 dBm at relative angle $180°$ in the middle of the left figure (wireless LAN card B, with human). Wireless LAN card B observes a more similar range of received signal strength distribution than wireless LAN card A.

On the other hand, wireless LAN card C has good receiver sensitivity compared to other cards. These surveys show clear differences of received signal strength distribution to each orientation and each wireless LAN card. The above positioning systems, which will develop in future ubiquitous environments, have to consider the differences of received signal strength distribution to each orientation and each wireless LAN card. Such consideration of the differences of received signal strength caused by these effects is one important key for useful positioning systems in ubiquitous environments where each user accesses her own terminal. We will continue these surveys to develop our orientation estimation method.

METHODOLOGY

In the preceding section we pointed out the variations in received signal strength distribution according to terminal orientation. Based on our observations in previous section, we propose an orientation estimation method by verifying the difference of received signal strength distribution. Our orientation estimation algorithm consists of the following two phases.

- **Survey Phase:** A user terminal with a wireless LAN adapter employs our survey software[4] to observe each access point's received signal strength at a certain state. Observed and received signal strength distributions are registered in a database. The system uses registered data in the estimation phase as pre-observation study data. We assume two methods to construct an observation database

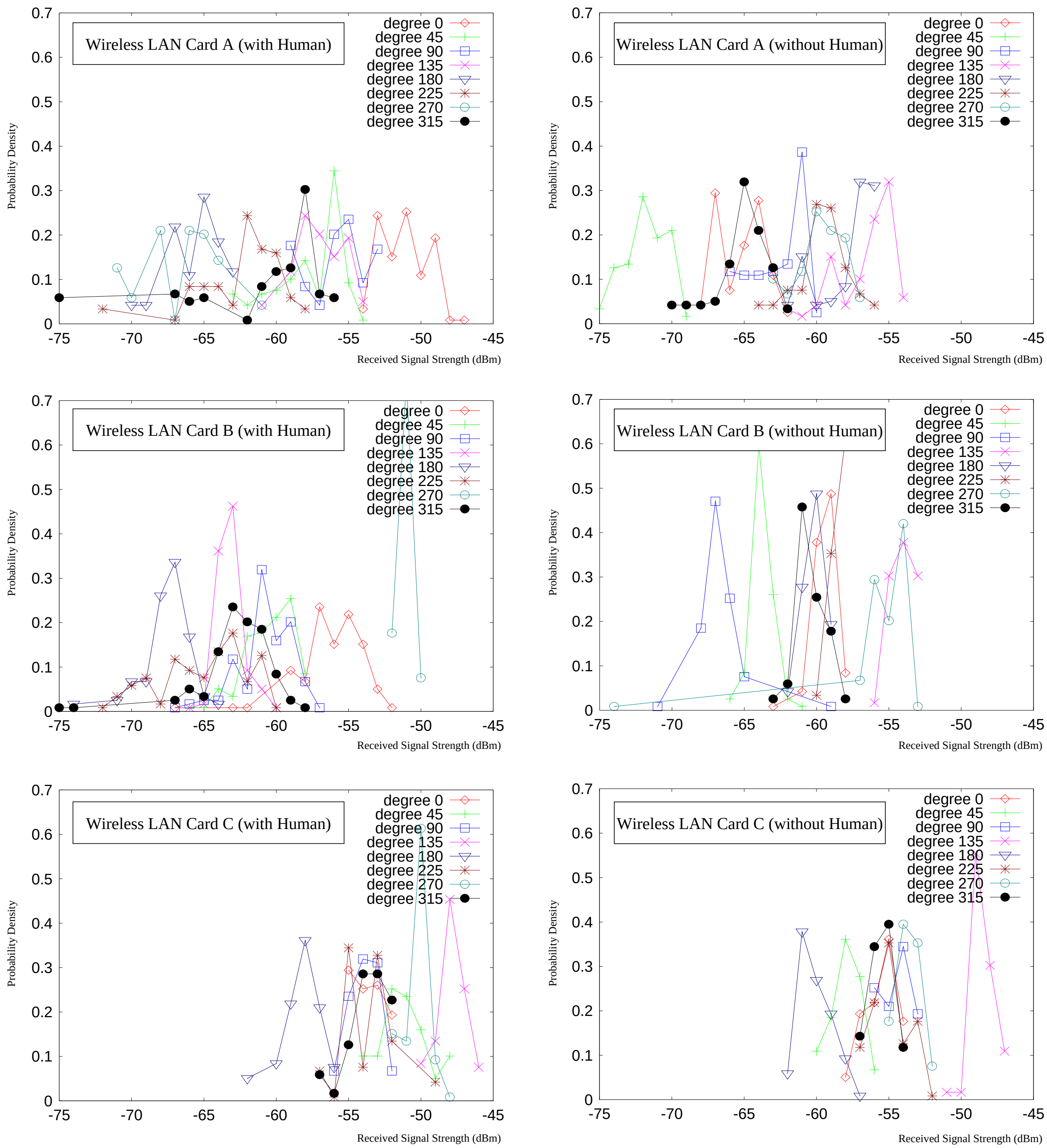

Fig. 4. Received signal strength distribution in each observation

in the survey phase. Service providers conduct pre-observation in their service area and construct a database. Another method is user collaboration, such as Place Lab [6] and Locky.jp [19]. Each user collects wireless LAN observations in each environment and accumulates these data in a central database. Each method has to consider the difference of received signal strength distribution among wireless LAN cards to share information. This problem is a work in progress. In the evaluations experiment, we examine estimated orientation accuracy when using the same wireless LAN card in the survey and estimation phases.

- **Estimation Phase:** In a particular state, a terminal that wants to know its orientation makes an observation for a given short length of time. The terminal estimates its orientation using the received signal strength distribution observed in the survey and the estimation phases. For orientation and location estimation in daily use, a user does not conduct the survey phase. Instead, she downloads a received signal strength database in the survey phase and only conducts the estimation phase.

Each phase in orientation estimation

In this section, we describe the details of the survey and estimation phases.

1) Survey Phase: In the survey phase, a terminal pre-observes received signal strength distribution at each state, and the pre-observation data is registered in the database as a pre-observation model. First, we define state set S, in which S is defined by a set of state s_i where users observed the received signal strength of an access point in a survey phase.

$$S = \{s_1, s_2, s_3, ..., s_k\}. \tag{1}$$

Each state s_i shown in (1) consists of three elements: θ_i is orientation, and $x_p and y_p$ are terminal coordinates, given by our wireless LAN and Bayesian based location estimation system [3]. (k is the number of states).

$$s_i = (\theta_i, x_p, y_p). \tag{2}$$

Second, we define observation set O, where O consists of each observation o. In certain state s_i, a terminal observes the received signal strength of each access point. Each observation o consists of MAC address β and value of received signal strength α (n is the number of access points, and m is the number of observation counts).

$$O = (o_1, o_2, o_3, ..., o_m). \tag{3}$$

$$o_i = \{(\beta_1, \alpha_{1i}), (\beta_2, \alpha_{2i}), (\beta_3, \alpha_{3i}), ..., (\beta_n, \alpha_{ni})\}. \tag{4}$$

From expressions (3)(4), we can calculate conditional probability $P(\alpha|\beta, s_i)$. $P(\alpha|\beta, s_i)$ is the conditional probability in a certain state s_i whereby the user can observe received signal strength α from MAC address β chance of $P(\alpha|\beta, s_i)$. The conditional probabilities of each access point are collected as pre-observation data and accumulated in the database.

$$\begin{aligned} &P(\alpha|\beta, s_i) \\ &= \frac{Number\ of\ \alpha\ from\ \beta\ observed\ in\ states_i}{Number\ of\ \beta\ observed\ in\ state\ s_i} \end{aligned} \tag{5}$$

2) Estimation Phase: In the estimation phase, a terminal observes the received signal strength of access points. We define this state as s_j, which consists of terminal orientation θ_j and coordinates x_p, y_p. (x_p and, y_p are given by our location estimation system using a wireless LAN.)

$$s_j = (\theta_j, x_p, y_p). \tag{6}$$

In state s_j, a terminal observes received signal strength for a given short length of time. This observation is defined as O_1. From observation O_1, the system calculates conditional probability $P_{O_1}(\alpha|\beta, s_j)$ shown in expression (5) to each access point. Next, we define observation O_2, which is each state s_i in the survey phase. Then the system calculates conditional probability $P_{O_2}(\alpha|\beta, s_i)$ using expression (5). From O_1 and O_2, we also define Λ_1, Λ_2, and set Q.

$$\Lambda_1 = \ Observed\ set\ \alpha\ from\ \beta\ in\ O_1. \tag{7}$$

.

$$\Lambda_2 = \ Observed\ set\ \alpha\ from\ \beta\ in\ O_2. \tag{8}$$

.

$$Q = \{q|q{\in}\Lambda_1{\cup}\Lambda_2\}. \tag{9}$$

. From (7), (8), and (9), conditional probability can be expressed as follows:

$$P_{O_1}(Q) = P_{O_1}(\alpha|\beta, s_j). \tag{10}$$

$$P_{O_2}(Q) = P_{O_2}(\alpha|\beta, s_i). \tag{11}$$

Using expressions (10) and (11), and Jensen-Shannon Divergence [10], we define the divergence of each received signal strength distribution.

$$\begin{aligned} &JSD(P_{O_1}(Q), P_{O_2}(Q)) \\ &= \frac{1}{2}[D(P_{O_1}(Q)||ave_{P_{O_1}(Q),P_{O_2}(Q)}) \\ &\quad +D(P_{O_2}(Q)||ave_{P_{O_1}(Q),P_{O_2}(Q)})]. \end{aligned} \tag{12}$$

In expression (12), $ave_{P_{O_1}(Q),P_{O_2}(Q)}$is the average of $P_{O_1}(Q)$ and $P_{O_2}(Q)$.

$$ave_{P_{O_1}(Q),P_{O_2}(Q)} = \frac{P_{O_1}(Q) + P_{O_2}(Q)}{2}. \tag{13}$$

D is defined by Kullback-Leibler divergence [12].

$$D(P_{O_1}(Q)||P_{O_2}(Q)) = \sum_{q{\in}Q} P_{O_1}(q)\log\frac{P_{O_1}(q)}{P_{O_2}(q)}. \tag{14}$$

For example, if $P_{O_1}(Q)$ and $P_{O_2}(Q)$ have identical conditional probability, $JSD(P_{O_1}(Q), P_{O_2}(Q))$ equals 0. In our method, the system calculates the JSD value to each access point with (12), (13), and (14). The sum of all access point JSD values is considered the divergence of a certain observation. The system defines state s_i as having a minimum (15) value (that is, the highest degree of similarity) as the result of orientation estimation.

$$\begin{aligned} &Divergence(O_1, O_2) \\ &= \sum_{\beta=1}^{n} JSD(P_{O_1}(Q_\beta), P_{O_2}(Q_\beta)). \end{aligned} \tag{15}$$

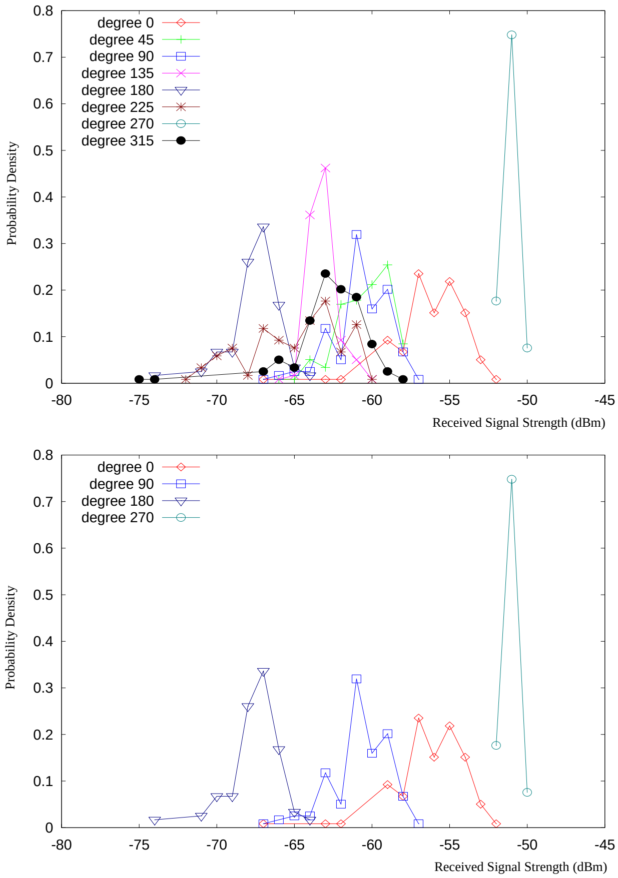

Fig. 5. Received signal strength distribution in 8- and 4-ways

EVALUATIONS

In accordance with the orientation estimation algorithm that uses the divergence of received signal strength distribution described in previous section, we implemented our orientation estimation system on a Java2 Platform Standard Edition 1.4.2. To verify our method's effectiveness, we conducted an evaluation experiment on our campus where more than three hundred access points have already been placed, allowing users access to wireless LAN everywhere on campus. When examining the results of received signal strength distribution, we see similar received signal strength distribution in 8-way (top of Fig. 5). The button of Fig. 5 shows received signal strength distribution in a 4-way. There are sharp differences to each orientation. Location and orientation based application need 4-way estimation at most. Therefore in this paper, we examine the accuracy of estimated orientation in 4- and 2-ways.

A. Experimental Setup

1) Hardware: We used the following hardware listed below. In this experiment, we used the same terminal in the survey and estimation phases and compared the accuracy of estimated orientation of our method.

- Laptop: Toshiba DynaBook SS3500 DS/EP/2
- Wireless LAN Card: PROXIM ORiNOCO 11a/b/g Combo Card

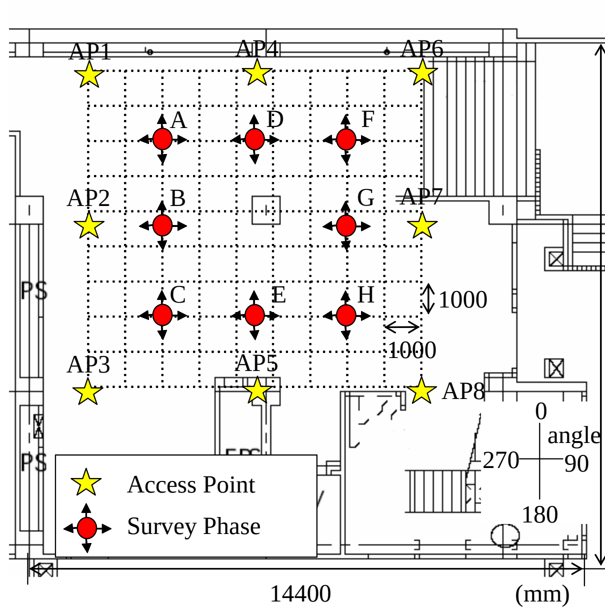

Fig. 6. Overall view of experimental environment

Fig. 7. Holding laptop in experiments

Wireless access points have already been installed in the buildings on our campus. The access point's beacon interval is 0.1 sec.

- Access Point: Colubris Networks CN-320,CN-300

2) Overall View of Experimental Environment: Figure 6 presents an overall view of the experimental environment in which stars denote the location of each access point and circles denote that a position survey phase was conducted. We defined the orientations $0°$ to $360°$ clockwise.

3) Survey Phase: We conducted 4-way received signal strength pre-observation at each point represented by the circles in Fig. 6. At each point, we observed the received signal strength for two minutes in each orientation: $\theta = 0°, 90°, 180°, and\ 270°$. In this experiment, a user held the laptop, as shown in Fig. 7, and observed received signal strength distribution.

4) Estimation Phase: In the estimation phase, we conducted three types of experiments to examine the effectiveness of our method and compared the accuracy of orientation estimation.

- Impact of request period
- Impact of access point allocation
- Total accuracy of location and orientation estimation.

Experiment 1: Impact of Request Period

The first experiment verified the request collection time for orientation estimation. Since our method uses the difference of received signal strength distributions between the survey and estimation phases, it is important to verify how long it takes to collect requests needed for practical use: a system that needs 1 min to request collection data for orientation estimation is too long. We conducted experiments with four time intervals: 2, 4, 6, and 12 sec for one request and compared orientation estimation accuracy according to the request collection time. Furthermore, we compared the estimated orientation accuracy in 2-way ($0°, 180°$ or $90°, 270°$ in Fig.6) and 4-way ($0°, 90°, 180°, 270°$ in Fig. 6) estimation. The allocation of access points was AP2, AP4, AP5, and AP7 in Fig. 6. The total number of requests was 8,320.

Figure 8 shows the results of experiment 1. The horizontal axis shows the request period, and the vertical axis shows the accuracy of estimated orientation in 2- and 4-ways. In two-second request collection experiments, we obtained 88% orientation estimation accuracy for 2-way and 77% for 4-way estimation. In four-second request collection experiments, we achieved 90% orientation estimation accuracy for 2-way and 79% for 4-way estimation. In six-second request collection experiments, we attained 92% orientation estimation accuracy and 83% for 4-way estimation. Finally, in 12-second request collection experiments, we achieved 95% orientation estimation accuracy for 2-way and 88% for 4-way estimation. When the system increases the request period for orientation estimation, estimated orientation accuracy also increases both 2- and 4-way estimation. Since the allowable request period differs by service, each service has to consider this point. For example, a service that forces users to frequently change orientation has to set a brief request period. In the results, the accuracy of estimated orientation decreases. If a service allows a long enough request period, a terminal can estimate orientation with high accuracy.

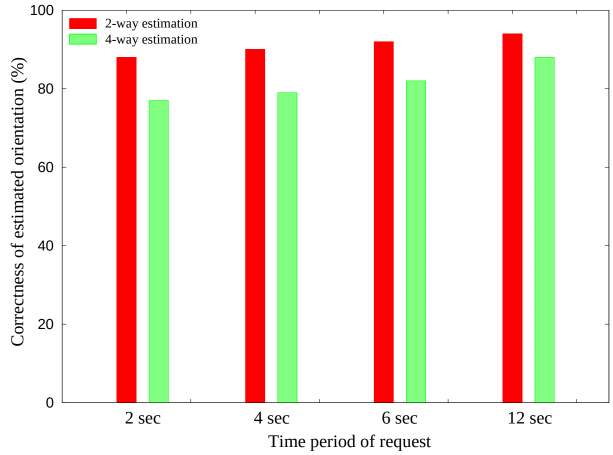

Fig. 8. Orientation estimation accuracy in each request period

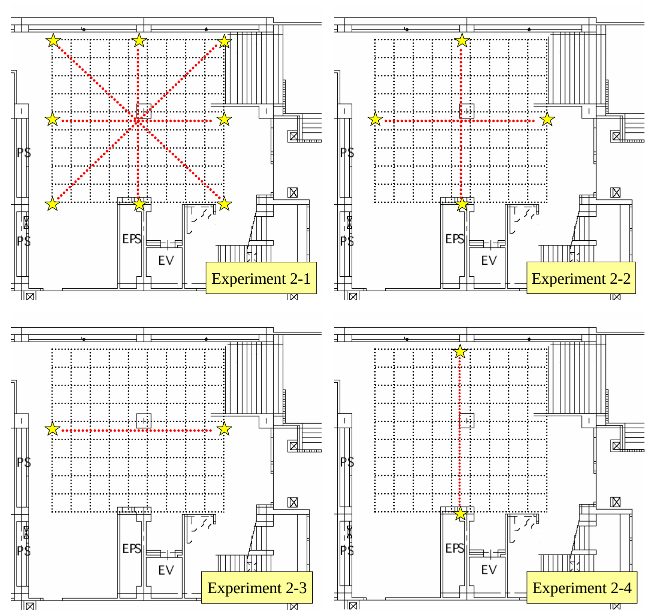

Fig. 9. Different allocation of wireless access points

Experiment 2: Impact of access point allocation

The second experiment relates differences among wireless access points. In some spaces, the user cannot collect enough received signal strength information. For example, a given location may get received signal strength information from eight access points while another might receive only two. Therefore, to compare the differences of access point settings, we experimented with the following four types of access point allocations (Fig. 9).

(Exp 2-1) Using all access points information.
(Exp 2-2) Using AP2, AP4, AP5, and AP7 information
(Exp 2-3) Using AP2 and AP7 information
(Exp 2-4) Using AP4 and AP5 information

In this experiment, we set the request period to six seconds and conducted 5120 orientation estimation requests.

Figure 10 shows the results of experiment 2. In experiment 2-1, we obtained 94% orientation estimation accuracy for 2-way and 85% for 4-way estimation. In experiment 2-2, which used four fewer access points than experiment 2-1, we achieved 92% orientation estimation accuracy for 2-way and 82% for 4-way estimation. In experiment 2-3, with only two access points, we attained 85% orientation estimation accuracy for 2-way and 68% for 4-way estimation. In experiment 2-4, which also used two access points but with different allocation than experiment 2-3, we achieved 83% orientation estimation accuracy for 2-way and 65% for 4-way estimation.

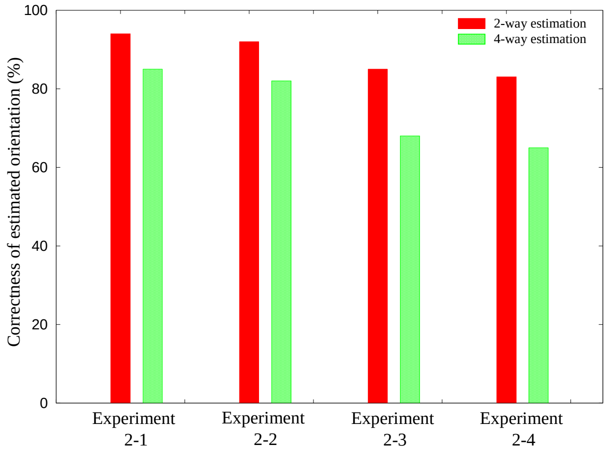

Fig. 10. Orientation estimation accuracy in each allocation

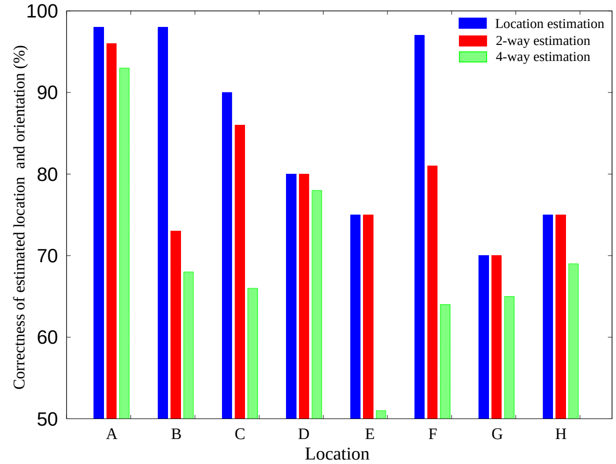

Fig. 11. Correctness of estimated location and orientation

Experiment 3: Location and Orientation Accuracy

Thirdly, we examined location correctness and orientation estimation only using a wireless LAN adapter. For positioning, we used our wireless LAN based positioning software [3]. We did location and orientation estimation experiments from points A to H in Fig. 6. In location estimation, if location estimation error is within 2.5 m, we consider it the right answer. In orientation estimation, if the system estimates real orientation, we consider it the right answer. We set the time period of requests to six seconds, and the allocation of access points was identical to experiment 2-1.

Figure 11 shows the results of experiment 3. The horizontal axis shows the location at which estimation was carried out, and the vertical axis shows estimation accuracy. (Location estimation results only show accuracy of location estimation. Orientation estimation results show the total accuracy of both location and orientation estimation). For example, location A has good total accuracy because both location and orientation estimation have good estimation accuracy. However, location E has only 75% location estimation accuracy and 69% accuracy of 4-way orientation estimation; total accuracy equals 51%. An indoor experiment environment is likely related to this point. Because of multipath and other effects, radio wave conditions vary widely in each location. Under such circumstances, our method achieved 81% total location accuracy and 2-way orientation estimation and 70% total accuracy in location and 4-way orientation estimation.

RELATED WORK

In this section, we describe related work in existing location estimation systems using wireless LAN and orientation-based services. Location estimation systems using Wireless LAN can be classified into the following three categories.

- **Cell-ID System:** This location estimation system uses access point communication areas (called cells) and considers access points at which a terminal connects to be the user's location. It is easy to establish this system because the terminal can estimate its location with only the access point's MAC address and location data. However, this system suffers problems with location estimation accuracy.
- **TDOA (Time Difference of Arrival) System:** In this system implemented on Air Location [18], multiple access points receive echoes, which are transmitted by the terminal. Each access point then calculates the received timing error and clock error. Finally, the system estimates the terminal's location. This system requires single-purpose access points.
- **Received Signal-Strength System:** This location estimation system depends on received signal strength. It can be further classified into more groups depending on how the signal strength is actually used.

  The RADAR [1] system observes signal strength from access points whose location is known. Then the system estimates positions using values and ideal values. They proposed both an empirical and a radio propagation method. In the empirical method, they consider user orientation. But they use received signal strength instead of received signal strength distribution. As mentioned earlier, the received signal strength of wireless LAN varies widely because of multipath, interference, reflection, refraction, and absorption by humans. Therefore, it is important to use received signal strength distribution for estimation. Our method is different because it considers this point.

  The WiPS [2] system assumes that all devices with wireless adapters (including access points, terminals, etc) are equal and estimates terminal locations to determine radio wave distance characteristics. Since the above systems estimate location using radio wave distance characteristics, they face multipath problems caused by interference, reflection, and other unpredictable interruptions.

  The Ekahau [5] and the PlaceLab [6] [7] systems estimate location by measuring signal strength preliminarily. The Ekahau system saves these data in a location estimation server, which then estimates the location when users make requests. They propose location-aware-services but not orientational-location-aware services that use orientational information.

The wireless LAN based positioning systems listed above have to consider the difference of received signal strength distribution caused by orientation, user, and wireless LAN card differences, as pointed out in this paper.

- **Active Belt:** Active Belt [13] is a novel belt-type wearable tactile display that can transmit directional information. This tactile display, which enables users to intuitively obtain directional information, is a belt-type wearable device optimized for mobile use, and it is very interesting because a user can feel physical signals from the belt and can receive orientation navigation services.
- **Azim:** Azim [14] [15] is a pointing-type, azimuth-based position estimation system proposed for use with orientational-based services. It calculates user position from marker and azimuth information from directional sensors. This pointing system is intuitive and easy to use. Its designers propose an interesting directional application that transfers images to multiple displays to point to specific objects

We introduced related work on orientation-based services that use the above particular hardware and direction sensors. However, we don't know of a wireless LAN based orientation estimation method using divergence of received signal strength distribution.

CONCLUSIONS

In this paper, we proposed an orientation estimation method that uses divergence of received signal strength distribution and enables users to obtain orientation and location information with only a wireless LAN adapter. Our results show:

1) There are differences of received signal strength distribution to each orientation because of human absorption, effects of the terminal itself, and the differences of wireless LAN cards.
2) By using the above differences, a terminal can estimate its orientation and position with high accuracy using only wireless LAN cards.
3) Since a wireless LAN has a wide range of received signal strength values at the same location to each orientation, it is better to increase the request period for estimation accuracy.
4) If a user only has a wireless LAN card instead of a particular direction sensor, she can estimate orientation and location with 80% estimation accuracy.

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