A Position Estimation Method Based on Position Fingerprint Using Directional Antennas

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***Abstract*—In this paper, we consider a position estimation method based on propagation characteristics of multipath fading. In the method, prior to the actual position estimation, we need to measure propagation characteristics at known positions and build a database (DB). Using DB, we estimate a terminal position based on the similarity of the propagation characteristics of the DB positions and the terminal position. We propose to adopt directional antennas to estimate the position more accurately with less number of known positions than the conventional method. In this paper, we evaluated the accuracy of the proposed method quantitatively via computer simulations. As a result of the evaluation, we found it is possible to estimate the position more accurately with less number of pre-measurement by adopting directional antennas than the conventional method.**

Keywords— estimation, Position fingerprint, Directional antennas, Correlation distance

I. INTRODUCTION

Recently, since wireless technologies are widely available, several services based on position information have been proposed. To realize these services, accurate position estimation methods are essential. A typical example of these methods is GPS (Global Positioning System). A GPS receiver can estimate its position by measuring the propagation time of radio signals from multiple satellites to the receiver, hence it is ineffective in indoor environments because shadowed and or multipath-affected signals are often difficult or impossible to use [1]. As alternative approaches, several position estimation methods based on position fingerprint of the radio wave propagation characteristics have been proposed [2-6]. In these methods, propagation characteristics are measured as database (DB) before the actual estimation of the position. Using DB as fingerprint, we can estimate the position of a target terminal based on the similarity of propagation characteristics of the target and DB. We consider, as the fingerprint, using Received Signal Strength Indicator (RSSI) variation generated by changing the antennas pattern of phased array antennas [7]. In this method, in order to realize high accuracy of the estimation, the spatial interval of the DB points, d, should be less than the correlation distance of the propagation characteristics. The correlation distance is defined as the distance where the spatial correlation coefficient of fading fluctuation becomes 0.5. Therefore, in order to realize accurate estimation, the distance to the nearest DB position should be less than the length. Consequently, a huge number of DB measurements are required. We propose using directional antennas to extend the correlation distance. The correlation distance depends on angular distribution of direction of arriving waves. As the width of the distribution decreases, the correlation distance extends. In this paper, we evaluate the accuracy of our proposed method by simulation.

II. SPARIAL CORRELATION CHARACTERISTICS OF FADING VARIATION

The position estimation method using position fingerprint of the propagation characteristics is based on the position dependency of the fading, which is characterized as the spatial correlation characteristics of the fading variation [8]. Fig. 1 shows the correlation coefficient of the fading variation between two positions in a propagation environment where radio waves arrive from the all around uniformly. According to Fig. 1, the correlation distance is about 0.2 wavelength (λ) which corresponds to 0.03 m at 2.4 GHz. As the result, more than 300 DB measurements are required to cover even 1.0 m^2 as position estimation area This number is impractically large so this method is unfeasible.

On the other hand, it is known that the correlation distance increases as the width of the angular distribution of the direction of arriving waves decreases. Fig. 2 shows the spatial correlation characteristics in a propagation environment where the direction of arrival of multipath waves follow a normal distribution (average angular direction:θ=10°, 90° and standard deviation:σ=5°,10°). We find that the correlation distance extends to more than 8.0 λ in the case where θ=10° and σ=10°. It corresponds to the length of 1.0 m at 2.4 GHz. Compared with Fig. 1, this length is approximately 30 times longer, thus it becomes easier to build DB for highly accurate position estimation. Meanwhile, compared with the case where θ=90° and σ=10°, it is 6 λ longer. Hence it appears that the correlation distance extends directionally as the width of the angular distribution becomes smaller. We propose to use directional antennas to realize the extension of the correlation distance.

III. Position Estimation Method Based on Position Fingerprint

In position estimation methods using propagation characteristics, as the fingerprint, RSSI and Angle Of Arrive (AOA) are used generally [9]. These methods consist of the following two stages. The first stage is the pre-measurement stage where we measure propagation characteristics at known positions and build DB. The second stage is the position estimation stage where we measure propagation characteristics at the target position. Then we evaluate the similarity between the propagation characteristics of DB and the target. We assume the DB position having the highest similarity is the estimated position. The position fingerprint method generally provides relatively higher estimation accuracy even in a multipath environment.

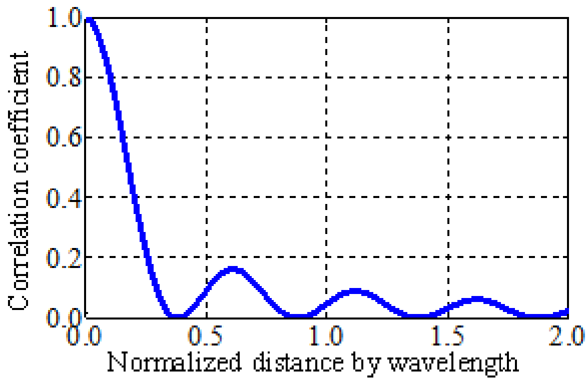

Fig. 1 Spatial correlation characteristics of fading variation where radio waves arrive uniformly from the all around

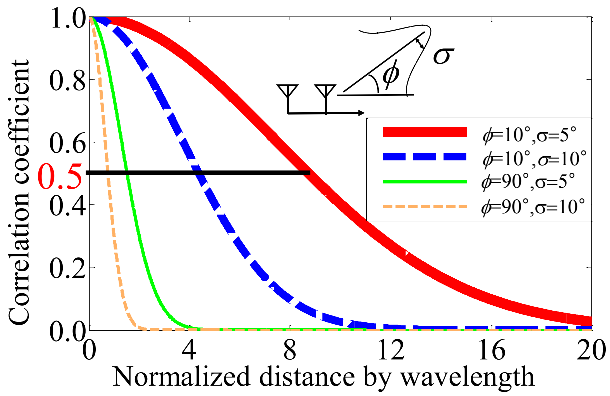

Fig. 2 Spatial correlation characteristics of fading variation where direction of radio waves follows a normal distribution

As mentioned above, the decrease of the width of the distribution extends the correlation distance. In order to realize the effect, we propose to adopt directional antennas. As the consequence, it becomes obviously possible to estimate a position more accurately even when we set less DB positions compared with the omni-directional antenna. However the correlation distance extends in a certain direction, thus the accuracy of estimation decreases in a certain direction . To solve this problem, we propose to change the direction of directivity of antenna (θ[°]) for a certain times to measure the RSSI variation and the correlation coefficient. As the directivity of the array antenna, we set the element patterns in the simulation. Each element of the array antenna has the same pattern. We assume that the directional pattern of the element is ideal, that is, each element receives signals arriving only within the beamwidth (*bw*). We change θ_n N times at a constant interval as follows (θ_n:*n*-th θ).

$$\theta_n = 360\frac{n}{N} \quad (n=1,\cdots N) \tag{1}$$

N is the number of direction of directivity of antenna to estimate each target points. For example when N is 3, we use θ_n (n=1, 2, 3) =0°, 120°, and 240°. After measuring RSSI sequences at each DB positions and the target position N times, we calculate the N correlation coefficient and take the average of them. In the proposed method, we determine the DB position giving the highest average correlation coefficient as the estimated position.

IV. Evaluation Method of Position Estimation using Directional Antennas

In this paper, we use the ray-tracing method to simulate propagation environment of a two-dimensional area. The simulation environment is depicted in Fig. 3. We compose a two-dimensional room model (size: 10.0 × 8.0 m) surrounded by concrete wall. In the ray-tracing, we consider reflections by the walls up to 6 times. A transmitter is located at (1.0, 1.0) m. In this room, we set the evaluation area (size: 1.0 × 1.0 m) where we evaluate the performance of the proposed method. The center of the area is located at (6.0, 6.0) m. In this area, we set the DB positions at a certain interval d and the target position randomly. We use phased-array combining of directional antenna elements. By changing the feeding phases randomly, the array pattern is also randomly varied. It generates the variation of RSSI. We generate an RSSI sequence by repeating the randomly-selected additional phases and use the sequence as a position fingerprint. The length of the sequence, which is the repeating number of the RSSI measurement, is 128 [7]. We use 4 elements phased array arrangement placed on a square form as shown in Fig. 4. The separation of elements is 0.125 m which is a wavelength at 2.4GHz.

At the pre-measurement stage, we generate an RSSI sequence at each DB position. At the position estimation stage, we use the same phases of the phased array to generate an RSSI sequence at the target position. Then, we calculate the correlation coefficient between RSSI sequences of the DB positions and the RSSI sequence of the target position. We repeat the above process N times with changing θ, then we calculate N correlation coefficients at each DB position. By calculating the average of the N correlation coefficients at every DB position, we determine the DB position having the highest average value of correlation coefficient as the estimated position. We regard the distance between the estimated position and the real position of the target as the estimation error. We repeat the above estimation process with changing the target position 1000 times, then calculate the average of the error and use it as the indicator of the estimation accuracy.

V. Performance Evaluation of Proposed Position Estimation Method

First, we show the relationship between the angular distribution of the direction of arrival of the received waves and the spatial distribution of the correlation coefficient of the propagation characteristics. Figs. 5 and 6 show the spatial distribution of the correlation coefficient of the RSSI sequences between the center of the evaluation area and the other positions. Fig. 5 is the case where θ=0°and *bw*=40° and Fig. 6 is where θ=90° and *bw*=40°. The both figures show each correlation distance extends in θ. However, in Fig. 5, there are other positions having a high value of correlation coefficient except for positions located around the center of the evaluation area. We consider the number of rays each element receives. The number of rays received at the center of evaluation is 15. There is a big difference compared with the situation on Fig.2. On the other hand, in Fig. 6, the width of the correlation distance is expanded compared with that in Fig. 5.

The average estimation error with the change of *d* is shown in Fig. 7. The minimum error means the average distance between each target position and the nearest DB position. The figure shows the higher estimation accuracy is realized by the proposal method than that by the omni-directional antenna. Moreover, the average estimation error becomes smaller as *N* increases. CDF (Cumulative Distribution Function) of the estimation error when *d* is 0.15 m is shown in Fig.8. Compared with the omni-directional case, the ratio of the target positions where we could estimate more accurately increases by directional antennas.

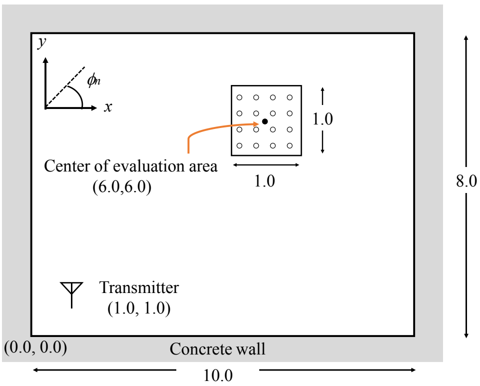

Fig. 3 Room model

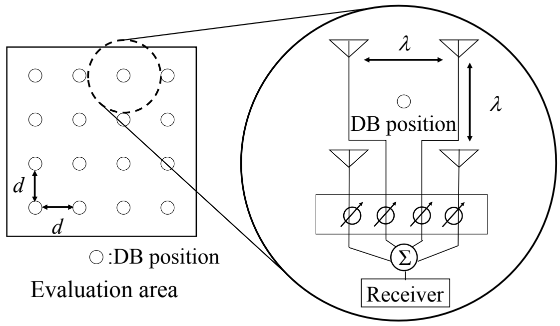

Fig. 4 Evaluation area and array antennas

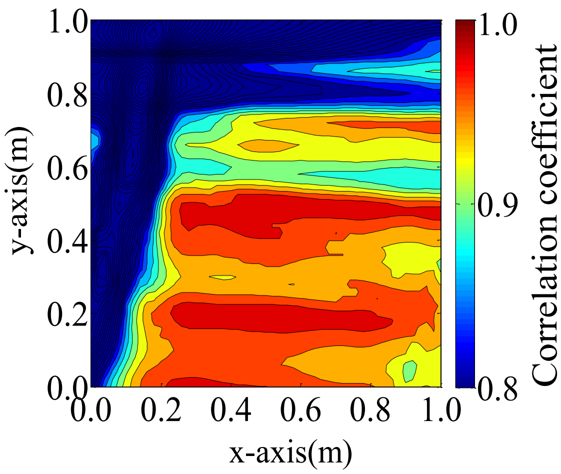

Fig. 5 Spatial distribution of correlation coefficient (θ=0°)

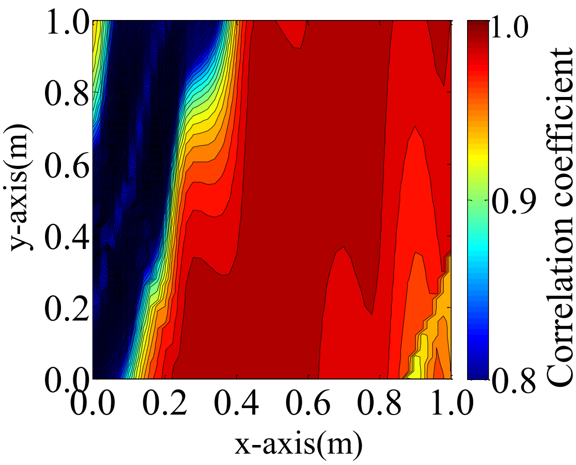

Fig. 6 Spatial distribution of correlation coefficient (θ=90°).

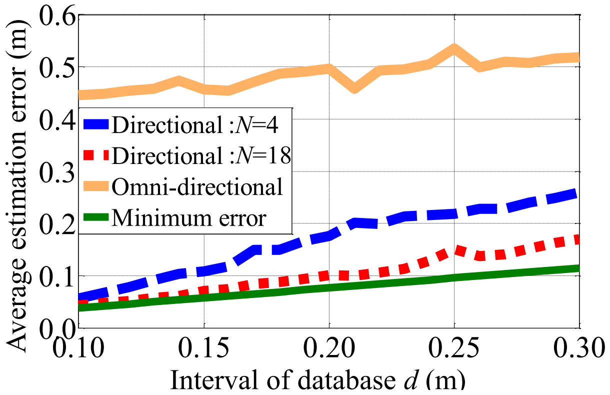

Fig. 7 Average estimation error

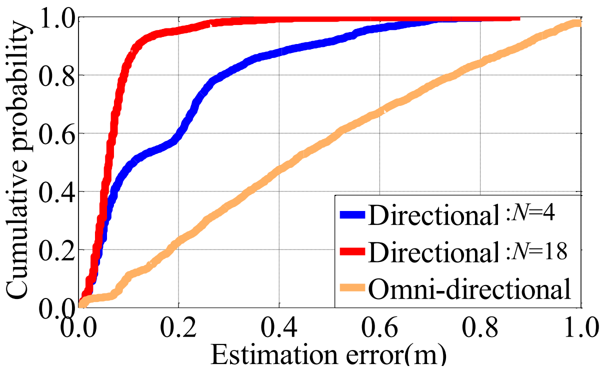

Fig. 8 CDF of estimation error (*d*=0.15 m).

VI. Summary

In this paper, we evaluate the accuracy of the position estimation method based on position fingerprint using directional antennas. The variation of RSSI generated by a phased array antenna is utilized as the position fingerprints. In this method, RSSI is measured as DB. As the directivity of the array antenna, we set the element patterns.

As the result of the evaluation, we show the performance of the proposed method. Using directional antennas, the positions are estimated more accurately compared with omni-directional antenna. Moreover, as the number of the element patterns increase, it is possible to estimate accurately even where the interval of DB is bigger.

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