Wireless Location Estimation Using Extended Fingerprinting Techniques in Indoor Environment

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1. Introduction

In recent years, methods of wireless location estimation in urban and indoor environment using array antenna have been attracting attention. One of the methods called location fingerprinting technique utilizes signal-subspace of received array data [1]. Terminal location is estimated by pattern matching of prepared database for the location fingerprints. This method enables us to estimate location of a terminal in NLOS environment. However, accuracy of the estimated location deteriorates when the propagation environment is varied and/or the reference data are not prepared at the location.

In this report, we propose an extended fingerprinting technique based on a high dimensional signal-subspace. The proposed method uses a propagation simulator to discriminate AOA of each multipath wave and estimates the terminal location using an approximate signal-subspace spanned by mode vectors of the multipath waves. Computer simulation results are provided to show availability of the proposed technique.

2. The Data Model

In this report, we employ an L-element linear array antenna shown in Fig.1. The received data vector of K-wave incidence can be written by

$$\boldsymbol{x}(t) = \sum_{k=1}^{K} \boldsymbol{a}(\theta_k)s_k(t) + \boldsymbol{n}(t) \tag{1}$$
$$= \boldsymbol{A}\boldsymbol{s}(t) + \boldsymbol{n}(t), \tag{2}$$
$$\boldsymbol{A} = [\boldsymbol{a}(\theta_1), \cdots, \boldsymbol{a}(\theta_K)], \tag{3}$$
$$\boldsymbol{s}(t) = [s_1(t), \cdots, s_K(t)]^T, \tag{4}$$
$$\boldsymbol{n}(t) = [n_1(t), \cdots, n_L(t)]^T, \tag{5}$$

where $\boldsymbol{a}(\theta_k)$ is the mode vector, $\boldsymbol{s}(t)$ is the complex amplitude vector, $\boldsymbol{n}(t)$ is the additive white Gaussian noise vector, and ^{T} denotes the transpose. The correlation matrix can be written by

$$\boldsymbol{R}_{xx} = E[\boldsymbol{x}(t)\boldsymbol{x}(t)^H], \tag{6}$$

where $E[\cdot]$ denotes the ensemble averaging and ^{H} is the complex conjugate transpose. The correlation matrix $\boldsymbol{R}_{xx}$ can be decomposed by the eigenvalues and the corresponding eigenvectors as

$$\boldsymbol{R}_{xx} = \sum_{i=1}^{L} \lambda_i \boldsymbol{e}_i \boldsymbol{e}_i^H = \boldsymbol{E}\boldsymbol{\Lambda}\boldsymbol{E}^H, \tag{7}$$
$$\boldsymbol{E} = [\boldsymbol{e}_1, \cdots, \boldsymbol{e}_L], \tag{8}$$
$$\boldsymbol{\Lambda} = \mathrm{diag}\{\lambda_1, \cdots, \lambda_L\}. \tag{9}$$

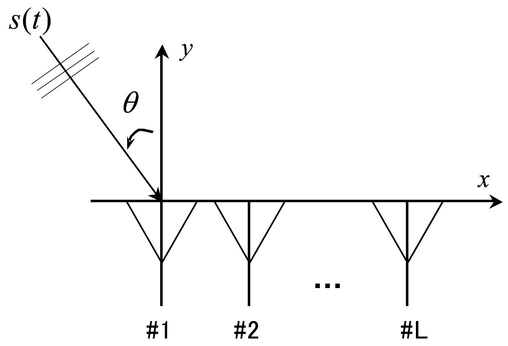


Figure 1: L-element array.

The space spanned eigenvector can be divided into signal-subspace and noise subspace. The matrix $\boldsymbol{E}_S$ and $\boldsymbol{E}_N$ consisting of the signal and the noise eigenvector, respectively, can be written by

$$\boldsymbol{E}_S = [\boldsymbol{e}_1, \cdots, \boldsymbol{e}_D], \tag{10}$$

$$\boldsymbol{E}_N = [\boldsymbol{e}_{D+1}, \cdots, \boldsymbol{e}_L], \tag{11}$$

where D is the number of the dominant signals ($D \leqq K$), that can be estimated by the relation of eigenvalues as follows

$$\lambda_1 \geqq \lambda_2 \geqq \cdots \geqq \lambda_D >> \lambda_{D+1} \geqq \cdots \geqq \lambda_L. \tag{12}$$

3. Location Estimation Using Signal Subspace

3.1 The Conventional Method

Received multipath signals transmitted by the antenna of a radio terminal are coherent, thus the signal subspace has the dimension of 1. The conventional method estimates the location using this one-dimensional signal-subspace as the reference signal subspace estimated by the known location. The conventional method uses following evaluation function

$$\cos\alpha_m = |\boldsymbol{u}_m^H \boldsymbol{v}|, \quad m = 1, 2, \cdots, N_{RP}, \tag{13}$$

where $\boldsymbol{v}$ is a vector of the received signal and $\boldsymbol{u}_m$ is a vector of the reference signal. N_{RP} denotes the number of reference points. These vectors are normalized by their magnitudes ($|\boldsymbol{u}_m| = |\boldsymbol{v}| = 1$). Terminal location can be estimated by the reference point having maximum value of (13).

3.2 The Proposed Method

In this subsection, we describe the proposed method briefly. The proposed method uses a simulator based on ray-tracing method to obtain AOA of the received multipath waves for each reference point.

Here, we assume that $\theta_1, \cdots, \theta_D$ are the AOAs of the direct and the multipath waves from a reference point, in this case, the approximate signal-subspace for the reference point can be obtained by

$$\boldsymbol{P}_S = \boldsymbol{A}(\boldsymbol{A}^H\boldsymbol{A})^{-1}\boldsymbol{A}^H, \tag{14}$$

$$\boldsymbol{A} = [\boldsymbol{a}(\theta_1), \cdots, \boldsymbol{a}(\theta_D)]. \tag{15}$$

The proposed method uses the database in which each signal subspace is defined by (14). The terminal location is estimated by

$$\cos\alpha_m = |\boldsymbol{v}^H \boldsymbol{P}_{Sm} \boldsymbol{v}|^{\frac{1}{2}}, \quad m = 1, 2, \cdots, N_{RP}. \tag{16}$$

The conventional method estimates the terminal location using one dimensional reference signal-subspace defined by the sum of the direct and the multipath waves. Therefore, since phase difference

Table 1: Propagation environment parameters.

Room depth & width	9 [m] × 7 [m]
Number of maximum reflection	3 (Using Ray-Tracing)
Number of reference point	528
Wall reflection	Fresnel reflection (TE incidence)
Relative permittivity of wall	6.25
Electroconductivity of wall	0.0814 [S/m]

Table 2: Simulation parameters.

Receiving array form	ULA
Number of array elements	8
Element separation	0.5 wave length
Frequency	2.4 [GHz]
SNR	∞ (Database construction) 20 [dB] (Location estimation)
Number of snapshots	512

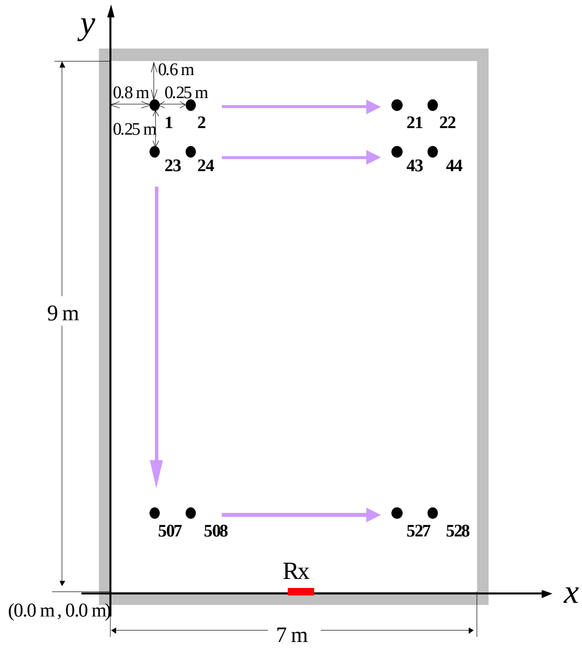


Figure 2: Propagation environment model (2-D model).

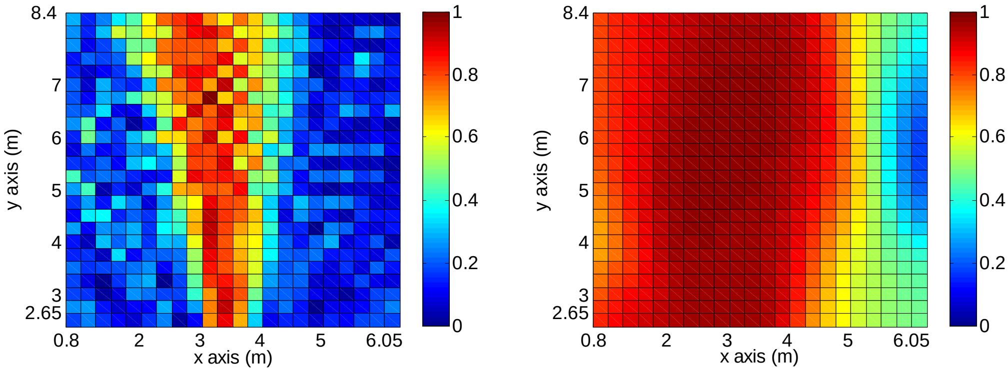
of each multipath wave is sensitive to path-length and reflection/diffraction coefficients, signal-subspace of each reference point often changes drastically at actual estimation. For this reason, the positioning accuracy deteriorates at the locations where the reference data are not provided. In contrast, the proposed method estimates the terminal location using the D-dimensional approximate signal-subspace spanned by the mode vectors of the multipath waves. Therefore, the proposed method can realize robust estimation with sparse reference points. Furthermore, the proposed method is also efficient even when propagation environment is varied [2].

4. Simulation

In this section, we show computer simulation results to evaluate the positioning accuracy of the conventional and the proposed method. Here, we evaluate 2-D location estimation accuracy for simplicity. In this simulation, indoor propagation environment is assumed as shown in Fig.2. Parameters of the room are listed in Table.1, and the simulation parameters are listed in Table.2.

Figure 3 shows the value of the evaluation function (13) and (16) where the wireless terminal is located on (x, y) =(3.05 m, 6.90 m). As shown in these figures, the conventional method shows clear peak at the terminal location. This means that the database with fine mesh is required for this approach. In contrast, the proposed method shows large value of evaluation function at the terminal location and its neighborhoods. This means that the proposed method will estimate the terminal location more robust than the conventional method.

Next, we show the location estimation results of the conventional and the proposed method with various number of the reference points. Here, we consider the cases that the number of reference point N_{RP} is 528, 132 and 64. The reference point separation (Δd) is 2, 4 and 6 wavelength in each case. The number of the evaluating point in estimation is 528 that corresponds to the reference points for N_{RP} = 528. Figure 4 shows Cumulative Distribution Function (CDF) of location estimation error for each N_{RP}. In this figure, the positioning accuracy of the conventional method rapidly deteriorates as decreasing of N_{RP}. However, the positioning accuracy of the proposed method is almost stable in these results. As the results, it can be said that the proposed method realize more robust location estimation method than the conventional method.



(a) Conventional method　　　(b) Proposed method

Figure 3: Estimation results in the ideal environment: Terminal location (x, y) =(3.05 m, 6.90 m).

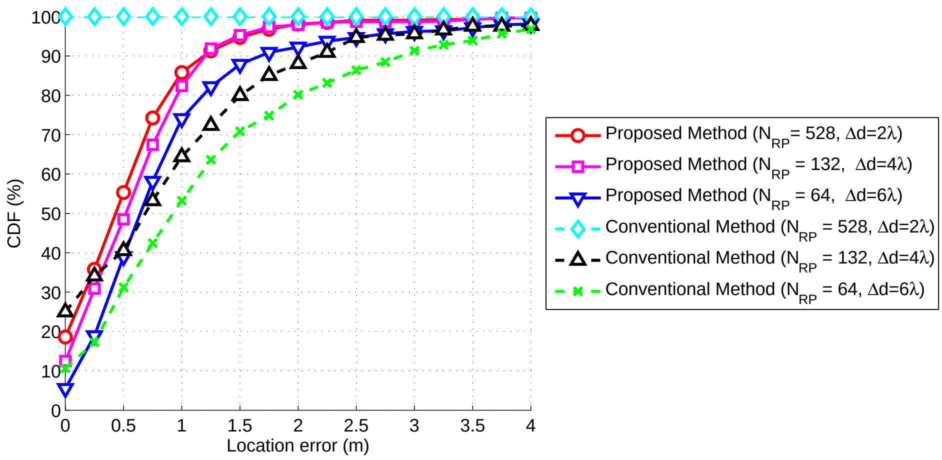


Figure 4: CDF of location estimation error with diverse number of reference point (N_{RP}).

5. Conclusion

In this report, we proposed the extended location fingerprinting techniques. The proposed method uses the simulator to derive database of higher dimensional signal-subspace by using AOA of each multipath wave and estimates the terminal location using the approximate signal-subspace spanned by the mode vectors. We show that the proposed method can realizes more robust location estimation method than the conventional method.

Acknowledgments

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References

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