Mobile Station Location Measurement by MUSIC Algorithm using Mode vectors considering angular spread

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Abstract

In wideband mobile communications, the high precision mobile station detection method based on measuring the direction of electric waves using by MUSIC algorithms was proposed. On the other hand, in order to increase the detection accuracy of angle of arrival(AOA) *under multi-path environments, MUSIC algorithm using mode vectors considering angular spread was proposed. In this paper, we propose a Laplace distribution based mode vectors, which are obtained when the angular spread is assumed as the Laplace distribution, and evaluate the mobile station location detection accuracy using the proposed mode vectors based MUSIC algorithm.*

1. INTRODUCTION

In wideband mobile communications, the establishment of the high precision mobile station detection technology using only with the mobile system, without using GPS, is an important subject. Measuring the direction of mobile station is an approach to this subject.

We proposed a mobile station detection method based on measuring the arrival direction of electric waves using by the MUSIC algorithm[1].

Generally, the arrival waves to the base station have the angular spread under multi-path environments. Because of this angular spread, the estimation error of the MUSIC algorithm is often large.

On the other hand, in order to increase the detection accuracy of angle of arrival(AOA) under the multi-path environments, the MUSIC algorithm using mode vectors considering angular spread was proposed[2].

In this paper, we propose a Laplace distribution based mode vectors, which is obtained when the angular spread is assumed as the Laplace distribution. Then, we evaluate the mobile station detection accuracy using proposed mode vectors based the MUSIC algorithm in urban and suburban areas, and show that the proposed method can largely reduce estimation error compared with the general mode vectors without considering the angular spread.

Table 1: Field measurement parameters

		Urban area (Takebashi)	Suburban area (Chiba-New town)
Carrier frequency		3.35GHz	
Chip rate		50Mcps (Distance resolution value: 6m)	
Transmitter power		10W	
MS	Tx antenna	Co-linear antenna(Omni-direction)	
	Tx antenna height	3m	
BS	Rx antenna	Linear array antenna(M=16) Omni-direction Elements interval: half-wave length	Linear array antenna(M=12) Omni-direction Elements interval: half-wave length
	Rx antenna height	105m	50m

2. FIELD MEASUREMENTS

We carried out field measurements in two areas (Takebashi and Chiba-Newtown) in Japan. Takebashi is a typical urban area in Tokyo and Chiba-Newtown is a typical suburban area near Tokyo. Table 1 shows the field measurement parameters. The receiving antenna, a linear array type, was placed on the tops of buildings and the transmitting antenna, an omni-directional antenna, was mounted on the rooftop of a van. The measurement points were selected in non line-of-sight areas ranging from 0.5km to 2 km (radius) from the BS. We set the carrier frequency, f, to 3.35[GHz], chip rate, B, to 50[Mcps] (distance resolution=6[m]). In the urban area, the number, M, of elements was 16 (the number, K, of sub-arrays was 14). For the suburban area, M=12 and K=10. We measured the instant delay profiles in the range of 20 wavelengths, and obtained the average delay profile. Then we apply the methods measuring the direction of mobile station to this average delay profile.

3. METHODS MEASUREING THE DIRECTION OF MOBILE STATION

A. The MUSIC algorithm

The MUSIC algorithm can measure the arrival direction of electric waves by using an array antenna system[3]. Fig.1 shows array antenna. Here, $M(m=1,2,..,M)$ is the number of elements and d is element interval, λ is the wave length. Assuming that Q paths arrive at the array antenna, the receiving signal can be expressed as

$$X(t) = AF(t) + N(t) \quad (1)$$

where A is the direction matrix, $F(t)$ is the amplitude vector, and $N(t)$ is the noise vector as follows

$$A = \left[a(\theta_1), \cdots, a(\theta_Q)\right] \quad (2)$$

$$a(\theta_q) = \left[1, \exp\left(-j\frac{2\pi}{\lambda}d\sin\theta_q\right), \cdots, \exp\left(-j\frac{2\pi}{\lambda}(M-1)d\sin\theta_q\right)\right]^T$$

$$(q = 1, 2, \cdots, Q) \quad (3)$$

$$F(t) = \left[F_1(t), \cdots, F_Q(t)\right]^T \quad (4)$$

$$N(t) = \left[n_1(t), \cdots, n_M(t)\right]^T \quad (5).$$

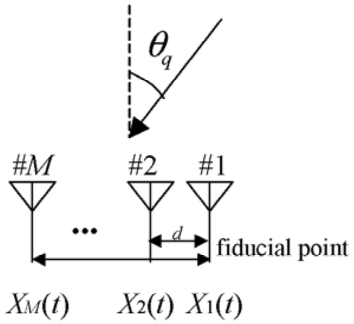


Fig. 1: Linear array antenna

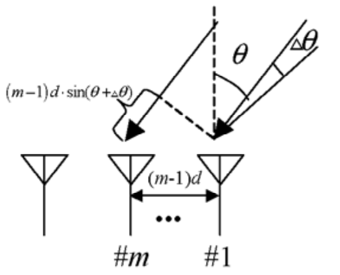


Fig. 2: The incident arrival angle model with extension

The amplitude and arrival direction of the q-th path are denoted $F_q(t)$ and θ_q, respectively. We define the correlation matrix of $X(t)$ as

$$R_{xx} \equiv \left\langle X(t)X^H(t)\right\rangle = ASA^H + \sigma_n^2 I \quad (6)$$

where $S = \left\langle F(t)F^H(t)\right\rangle$, σ_n^2 is the noise power and I is unit vector. < > denotes an ensemble average. Here, the eigen values and eigen vectors of R_{xx} are defined as $\lambda_m(m=1,2,\cdots,M)$ and $e_m(m=1,2,\cdots,M)$, respectively.
Let the eigen values decrease in size as follows

$$\lambda_1 \geq \lambda_2 \geq \cdots \geq \lambda_Q > \lambda_{Q+1} = \cdots \lambda_M = \sigma_n^2 \quad (7).$$

If the number of paths is Q, we can select the eigen vectors, $e_{Q+1},\cdots,e_M$, corresponding to the eigen values $\lambda_{Q+1},\cdots,\lambda_M$, whose power equal that of σ_n^2. Let the matrix that consists of these eigen vectors be E_N. Using E_N and mode vector $a_{MV}(\theta)$, MUSIC spectrum can be expressed as

$$P_{MU}(\theta) \equiv \frac{a_{MV}^H(\theta)a_{MV}(\theta)}{a_{MV}^H(\theta)E_N E_N^H a_{MV}(\theta)} \quad (8).$$

where $a_{MV}(\theta)$ is as follows,

$$a_{MV}(\theta) = \left[1, \exp\left(-j\frac{2\pi}{\lambda}d\sin\theta\right), \cdots, \exp\left(-j\frac{2\pi}{\lambda}(M-1)d\sin\theta\right)\right]^T \quad (9).$$

In this paper, we use the method of space averaging to suppress the coherency interference[4].

B. Laplace distribution based mode vectors

In actual environments, the arrival waves have some angular spread $\Delta\theta$ as shown in Fig.2. In these cases, the MUSIC algorithm using mode vectors considering angular spread instead of the general mode vectors eq. (9) was proposed and it was shown that proposed MUSIC algorithm can obtain a good performance.

An important problem is determining which mode vectors and angular spread should be used.

It is well known that the distribution of angular spread in actual environments is assumed with a Laplace distribution. Then we propose a Laplace distribution based mode vectors, which is obtained when the angular spread is assumed as the Laplace distribution.

At first, we derive the Laplace distribution based mode vectors. The Laplace distribution $P(\Delta\theta)$ is given as

$$P(\Delta\theta) = \frac{1}{4\sigma_s}\cdot\exp\left[-\frac{|\Delta\theta|}{2\sigma_s}\right] \quad (10)$$

where σ_s is the average angle or angular spread. The Laplace distribution based mode vectors can be expressed as

$$\begin{aligned} a_{MVm}(\theta) &= \int_{-\pi}^{\pi} P(\Delta\theta)\exp\left(-j\frac{2\pi}{\lambda}(m-1)d\sin(\theta+\Delta\theta)\right)d\Delta\theta \\ &\simeq \exp\left(-j\frac{2\pi}{\lambda}(m-1)d\sin\theta\right) \\ &\times\int_{-\infty}^{\infty}\frac{1}{4\sigma_s}\exp\left(-\frac{|\Delta\theta|}{2\sigma_s}-j\frac{2\pi}{\lambda}(m-1)d\cos\theta\Delta\theta\right)d\Delta\theta \\ &= \frac{\exp\left(-j\dfrac{2\pi(m-1)d\sin\theta}{\lambda}\right)}{1+\left(\dfrac{4\pi\sigma_s(m-1)d\cos\theta}{\lambda}\right)^2} \qquad (m=1,2,\cdots,M) \end{aligned} \qquad (11).$$

In eq. (11), the following relationship is used for small $\Delta\theta$.

$$\sin(\theta+\Delta\theta) \approx \sin\theta + \Delta\theta\cos\theta \quad (\Delta\theta \ll 1) \qquad (12)$$

In this paper, we apply equation (11) instead of equation (9) to equation (8).

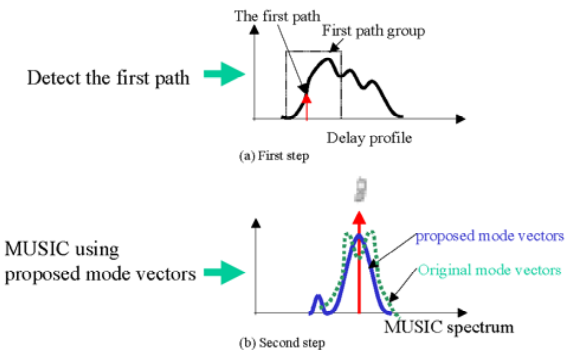
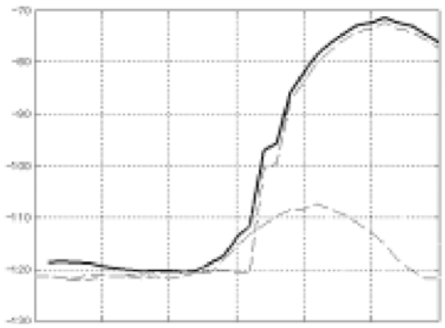


Fig. 3: The direction of mobile station



C. *Measuring the direction of a mobile station*

In order to predict the direction of mobile station, we proposed a new method. The propose method is constructed in two steps. Fig.3 shows the propose method. The first step is to detect the first travelling path in the measured delay profile. The second step detects the direction of the first travelling path by the proposed mode vectors based MUSIC algorithm and decide the direction of the mobile station from the peaks of the MUSIC spectrum.

D. *The first step*

We know that the direction of mobile station is most close to the direction of the first path. Since the first path is generally located ahead of the first path group, we detect the first path group in the measured average delay profile and then detect the first path from the first path group. Fig.4 shows an example of the first path group present in measured data with impulse response. From this figure, it is clear that the first path is located ahead of the first path group. We define the line of Noise level+ΔNoise; the intersection of this line and the first path group indicates the position of the first path. In this paper, we set ΔNoise=3[dB].

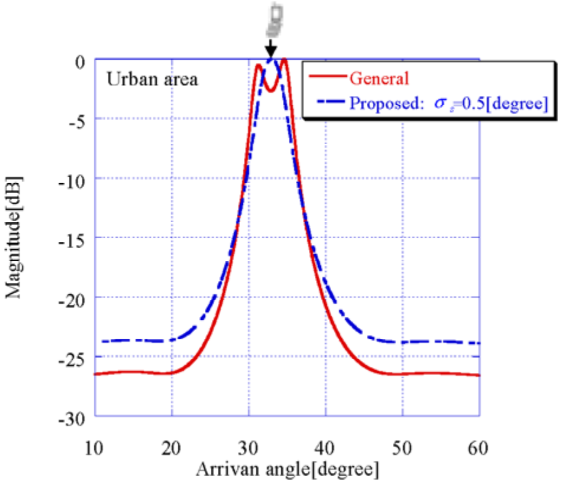


Fig. 5: MUSIC spectrum (Urban area)

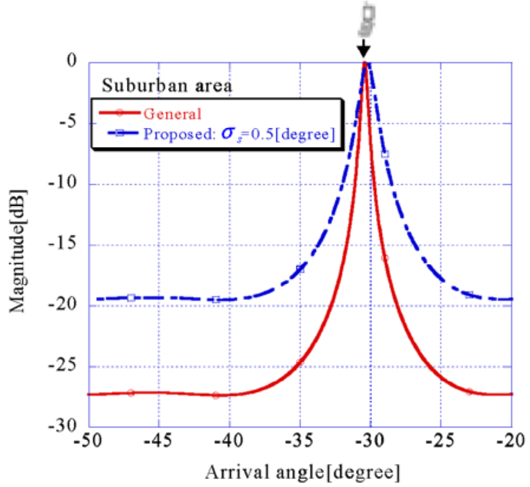


Fig. 6: MUSIC spectrum (Suburban area)

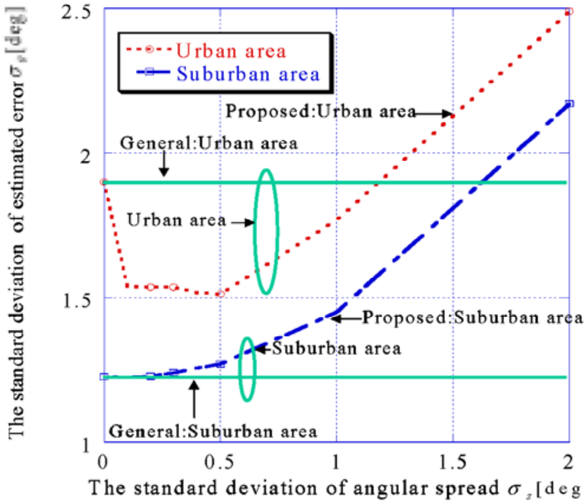


Fig. 7: the relationship between σ_s and σ_θ

is almost always only one path in the first path because there are fewer buildings around the MS.

Fig.7 shows the relationship between the angular spread σ_s and the standard deviation σ_θ of estimation error using the proposed method. This figure also shows the standard deviation of estimation error σ_θ using the general mode vectors. In urban area, when setting as $0^\circ < \sigma_s \leq 0.5^\circ$, proposed mode vectors based MUSIC algorithms can be remarkably improved the estimation accuracy.

On the other hand, in sub-urban area, when setting as $0^\circ < \sigma_s \leq 0.3^\circ$, the estimation accuracy is almost same as that using the general mode vectors.

From Fig.7, setting σ_s to the optimal values $\left(0.2^\circ \leq \sigma_s \leq 0.3^\circ\right)$, the estimation error can be improved compared with that of the general mode vectors.

5. Conclusion

We proposed a MUSIC algorithm with a Laplace distribution mode vectors, which are obtained when the angular spread is assumed as the Laplace distribution. Then, we evaluated the mobile station detection accuracy using the proposed mode vectors based MUSIC algorithm in urban and suburban areas and clarified that the proposed method can reduce estimation error compared with the MUSIC algorithm with the general mode vectors.

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