Extension of a Received Signal Estimation Method at a Remote Location to a 3-Dimensional Space

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***Abstract* - An estimation method of a received signal at a remote location has been studied in a 2-dimensional space. The estimation method provided good estimation accuracy. In this paper, we expand the applicable environment to a 3-dimensional space. This paper shows a new estimation method for applying to a 3-dimensional space. In addition, we present the evaluation results of the estimation performance of the method when the assumed environment and the parameters of the estimation system are varied.**

***Index Terms* — Received signal estimation, MUSIC method, 3-dimensional space, Multipath environment.**

1. Introduction

The propagation properties such as amplitude and phase of a received signal vary significantly in a multipath fading environment. Therefore in general, we cannot estimate a received signal at a remote location over the correlation distance of the multipath fading. In other words, a received signal is local information which can be obtained only at a certain location. In this paper, a received signal means the radio propagation properties represented by the complex amplitude (amplitude and phase).

In recent years, various applications based on the radio propagation properties have been developed. If a received signal at a remote location can be estimated over the correlation distance, a wide variety of new applications can be possible. An example is a terminal position estimation method using position fingerprint [1]. The technique utilizes the locality of the multipath fading. On the other hand, if we can estimate signals at remote positions, we need not require fingerprint database which needs huge number of measurements in the position estimation method.

The estimation of a received signal at a remote location has been studied in a 2-dimensional space [2]. The previous study provides good estimation accuracy. However, the estimation method in a 3-dimensional space has not been yet established. Thus, our purpose is to expand the estimation method to a 3-dimensional space.

2. Estimation method in a 2-dimensional space

In [2], the directions of arrival (DOAs) are used for the estimation of a received signal at a remote location. In the existing estimation method for a 2-dimensional space, DOAs and the complex amplitudes of the arriving waves are estimated by the Multiple Signal Classification (MUSIC) method and the least squares method, respectively. Using the estimated DOAs and the complex amplitudes, a received signal at a remote location is estimated based on the plain wave assumption. The use of DOAs for a received signal estimation has not been considered in the other studies.

3. Estimation system and arriving wave model

In this paper for applying to a 3-dimensional space (a hemisphere), two uniform linear array antennas having N elements are arranged at right angles as shown in Fig. 1. We consider that each linear array antenna is placed on x- and y-axes. We assume L plain waves are arriving to the receiving points. The reference point is at a position where the reference phase of the signal is defined. The position of each antenna element and the coordinate of the target point (r, θ, φ) are assumed to be provided exactly.

The received signal at a remote location is estimated by the following procedure:

I. The incident angles of the l-th ($l = 1,...,L$) arriving wave to the two axes are estimated using N received signals at the individual antenna elements by the MUSIC method. The estimated angles are expressed as $\hat{\alpha}_{xl}$ and $\hat{\alpha}_{yl}$.
II. We consider all possible combinations of the zenith angle $\hat{\theta}_l$ and the azimuth angle $\hat{\varphi}_l$ of the l-th arriving wave from $\hat{\alpha}_{xl}$ and $\hat{\alpha}_{yl}$. Using $2N$ received signals, a complex amplitude $\hat{F}_l$ of the arriving waves at the reference point is estimated by the least squares method for all possible combinations of $\hat{\theta}_l$ and $\hat{\varphi}_l$. The combination of $\hat{\theta}_l$ and $\hat{\varphi}_l$ giving the minimum square error is selected as the solutions and $\hat{F}_l$ given by the combination is adopted.
III. The complex amplitudes of the arriving waves at the target point are estimated by taking the phase difference between the reference and the target points into account. By adding all the estimated complex amplitudes at the target, the estimated received signal at the target is obtained.

Table 1 shows the parameters of the arriving wave model and the specifications of the estimation system.

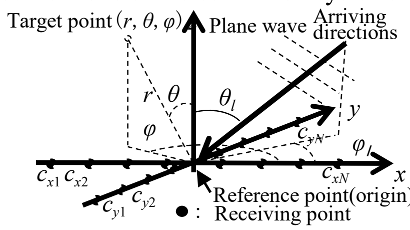

Fig. 1. Arriving wave model and estimation system.

TABLE I
Parameters of arriving wave model and specifications of estimation system.

Number of arriving waves	L = 1~6
Complex amplitude of each arriving wave	Amplitude : Unity Phase : Random (0°~360°)
Signal to Noise power Ratio (SNR)	40dB
Number of antenna elements	$2N$ = 8~50
Element separation	Half wavelength
Snapshots of MUSIC	40

4. Estimated results

Here we present the estimated results. We use the amplitude ratio defined by the following expression to quantify the estimation accuracy,

$$\text{Amplitude ratio} \quad 20\log|\hat{s}/s| \ \text{[dB]}, \qquad (1)$$

where s is the complex amplitude of the actual signal at the target point without the noise and $\hat{s}$ is that of the estimated.

Fig. 2 shows an example of the estimation. The figure shows the amplitude ratio for independent 100 trials where we change the phase of the arriving waves and the noise randomly. The distance to the target point from the reference point is changed as 0λ, 10λ, and 100λ where λ is the wavelength of the carrier frequency. In the figure, we assume $2N = 24$, $L = 3$, and the arriving directions $(\theta, \varphi) = (30°, 310°)$, $(10°, 10°)$, and $(55°, 50°)$. It can be seen from the figure that good estimation accuracy is provided at the target point within 10λ.

Fig. 3 shows the standard deviation of the amplitude ratio over 100 independent trials when the number of the antenna elements is varied. In the figure, the arriving directions are set randomly at every trial in the ranges of $0° \leq \theta_l \leq 60°$ and $0° \leq \varphi_l \leq 360°$. In addition, we assume L = 3 shown by the black lines and L = 5 by the red lines. The figure shows that the estimation accuracy improves as the larger number of the antenna elements. It also shows that the estimation accuracy deteriorates remarkably when the number of the arriving waves increases to 5 and the number of the antenna elements decreases to 15.

Fig. 4 shows the standard deviation when the number of the arriving waves is varied. In the figure, we assume $2N$ = 24 and the arriving directions are set randomly as in Fig. 3. In the figure, as the number of the arriving waves increases, the standard deviation increases. Especially noticeable deterioration of the estimation accuracy is seen at the distance of 10λ and 100λ.

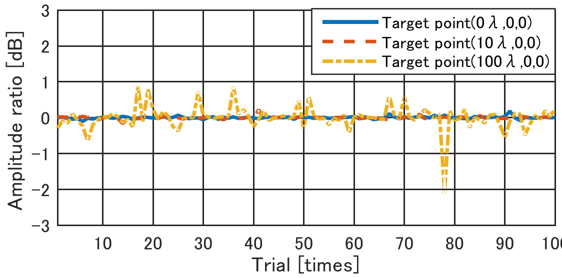

Fig. 2. Example of estimation.

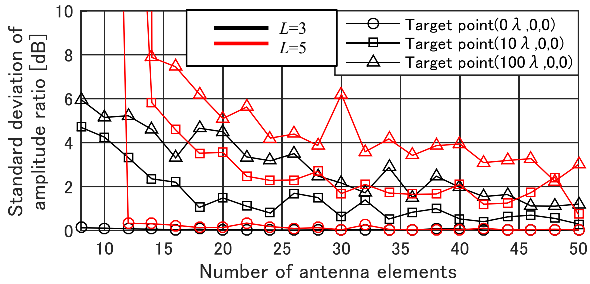

Fig. 3. Standard deviation of amplitude ratio for variation of antenna elements.

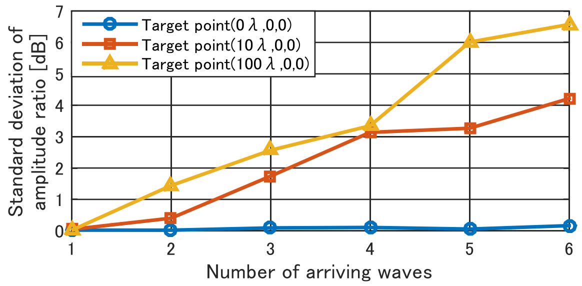

Fig. 4. Standard deviation of amplitude ratio for variation of number of arriving waves.

5. Conclusion

In this paper, we expand the estimation method of a received in a remote location to a 3-dimensional space. We present the estimation accuracy when the number of antenna elements and arriving waves are varied. We also investigate the number of the antenna elements to improve estimation accuracy deteriorated by increasing the number of the arriving waves and the distance from a reference point.

References

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[2] M. Tanaka, H. Iwai, and H. Sasaoka, "Estimation of received signal at an arbitrary remote location using MUSIC method," *IEICE Trans. Commun*, vol. E98-B, no. 5, pp. 806-813, May 2015.