# Direction of Arrival Estimation in FDTD Analysis of Radio Propagation Using MUSIC Method

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***Abstract*—In the ray-tracing method, radio propagation is approximately represented by using reflected and diffracted rays. Thus an arrival angle of incoming wave can be known easily by using the path of ray. On the other hand, in the FDTD method, a propagation wave is calculated strictly based on Maxwell's equations. Therefore, it seems difficult to know the arrival angle of incoming wave in the FDTD analysis. However, it is expected that the arrival angle of incoming wave can be obtained by using the direction of arrival estimation method in the FDTD analysis. In this paper, the direction of arrival estimation in the FDTD analysis of radio propagation using the MUSIC method is investigated.**

***Keywords—FDTD method; ray-tracing method; radio propagation; direction of arrival estimation; MUISC method***

## I. Introduction

Recently, in the development of electronic devices, a computer simulation is one of the important technologies.

It is important to know radio propagation characteristics in the development of wireless devices. Traditionally, as shown in Fig. 1, the ray-tracing method has been used to analyze radio propagation in the high frequency region. However, recently, the FDTD method can also be used to analyze these problems, because the computer performance was improved [1].

By the way, in the ray-tracing method, radio propagation is approximately represented by using reflected and diffracted rays. Thus an arrival angle of incoming wave can be known easily by using the path of ray. In the FDTD method, a propagation wave is calculated strictly based on Maxwell's equations. Therefore, it seems difficult to know directly the arrival angle of incoming wave from FDTD results.

On the other hand, it is expected that the arrival angle of incoming wave can be obtained by using the direction of arrival (DOA) estimation method in the FDTD analysis. However, in multipath environments with a single wave source, it seems that incoming waves at a receiver are correlated each other. Thus characteristics of DOA in the FDTD analysis of radio propagation are not clear.

In this paper, the DOA estimation in the FDTD analysis of radio propagation using the MUSIC method is investigated.

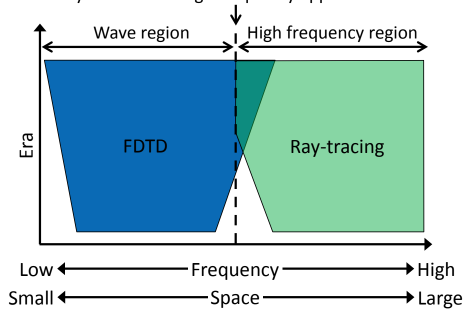



Fig. 1. Range of applications of the FDTD method [1].

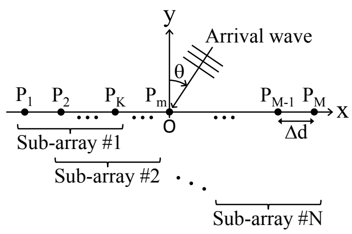



Fig. 2. Configuration of array antenna used in MUSIC method.

## II. Direction of Arrival Estimation in FDTD Analysis Using MUSIC Method

Traditionally, the beamformer method [2] and other estimation methods have been used for the DOA estimation. However, these methods have low resolution of arrival angle. On the other hand, the multiple signal classification (MUSIC) method is well known as high-resolution method for DOA estimation [3]. In this work, the MUSIC method is used for the DOA estimation in the FDTD analysis. This is referred to as "FDTD-MUSIC".

Fig. 2 shows a configuration of array antenna used in the MUSIC method. In this work, an equally spaced linear array antenna with $M$ elements is used. Here, when the interval between each element is denoted by $\Delta d$, and the wavelength is represented by $\lambda$, $\Delta d \leq \lambda/2$ should be satisfied. The forward/backward spatial smoothing preprocessing is used to make the decorrelation of incoming waves that are coherent for each other [4], [5]. Here, the number of sub-array elements is represented by $K$. In the MUSIC method, parameters such as $M$ and $K$ should be set to the appropriate value.

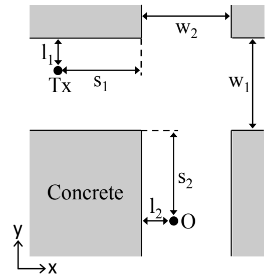



Fig. 3. Two-dimensional urban intersection model.

TABLE I. PARAMETERS OF INTERSECTION MODEL

| | | |
|---|---|---|
| **Road width** | $w_1$ | 18 m |
| | $w_2$ | 18 m |
| **Distance from intersection** | $s_1$ | 20 m |
| | $s_2$ | 5 - 40 m |
| **Lane position** | $l_1$ | 7.5 m |
| | $l_2$ | 7.5 m |

TABLE II. SIMULATION CONDITIONS

| | | | |
|---|---|---|---|
| **Frequency** | | | 760 MHz, 5.8 GHz |
| **Concrete [6]** | ***Relative permittivity*** $\varepsilon_r$ | | 7.0 |
| | ***Electric conductivity*** $\sigma$ | | 0.0473 S/m |
| **FDTD method** | ***Spatial increment*** | | 2.5 mm |
| **MUSIC method** | ***Num. of array elements M*** | | 181 |
| | ***Num. of sub-array elements K*** | | 77 |
| | ***Interval of antenna elements*** $\Delta d$ | ***760 MHz*** | 2.0 cm |
| | | ***5.8 GHz*** | 2.5 mm |
| **Ray-tracing method** | ***Max. num. of reflection*** | | 10 |
| | ***Max. num. of diffraction*** | | 1 |
| | ***Diffraction coefficient*** | | UTD method |

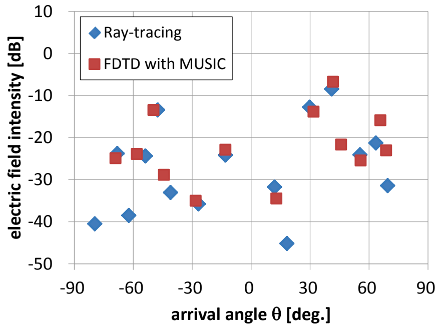
In field experiments of DOA estimation, the received signal is observed by using an array antenna placed in the field. Hence, interval of antenna elements $\Delta d$ is restricted by antenna size and so on. On the other hand, in the FDTD-MUSIC, the electric field intensity at appropriate observation points is observed instead of using antenna elements. Therefore, it has the advantage that the interval of observation point in the FDTD-MUSIC is not restricted compared with field experiments.

## III. NUMERICAL RESULTS OF DIRECTION OF ARRIVAL ESTIMATION IN URBAN INTERSECTION

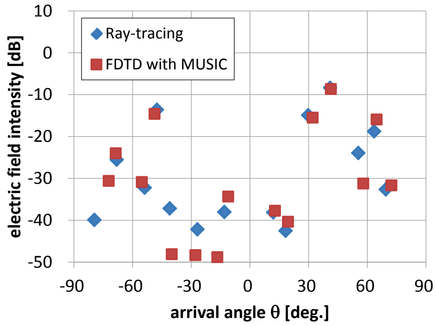
In this section, numerical results of DOA estimation obtained by the FDTD-MUSIC are compared with that obtained by the ray-tracing method. Two-dimensional analysis is performed to clarify fundamental properties of DOA estimation.

Fig. 3 shows a two-dimensional urban intersection model used in this work. In this model, it seems that incoming waves at the observation point O are correlated each other. Tables I and II show parameters of intersection model, and simulation conditions, respectively. In this simulation, arrival angle θ and electric field intensity of incoming waves at the observation point O are estimated.

Fig. 4 shows estimation results of arrival angle θ and electric field intensity at urban intersection for 760 MHz and 5.8 GHz, respectively. Here, as an example, the case of $s_2$ = 30 m is shown. As shown in these figures, it seems that arrival angle θ and electric field intensity obtained by the FDTD-MUSIC denote the same tendency as these obtained by the ray-tracing method for both 760 MHz and 5.8 GHz.




(a) 760 MHz




(b) 5.8 GHz

Fig. 4. Estimation results of arrival angle θ and electric field intensity at urban intersection in case of $s_2$ = 30 m.

## IV. CONCLUSIONS

In this paper, the direction of arrival estimation in FDTD analysis of radio propagation using the MUSIC method was investigated. As a result, it was seen that the DOA estimation in the FDTD analysis using MUSIC method indicates the same tendency as the ray-tracing method for an urban intersection used in this work. In the near future, the DOA estimation in three-dimensional FDTD analysis of radio propagation will be investigated.

## ACKNOWLEDGMENT

This work was supported by JSPS KAKENHI Grant Number 26420335.

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