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Fast MIMO channel calculation technique for multi-antenna system using spread spectrum technique for FDTD method

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Abstract: In this letter, we present a new method that combines the spectrum spreading technique and FDTD (Finite-Difference Time-Domain) simulation for reducing the computation time in multiple-antenna analysis. In this method, signals for the multiple antennas are generated by multiplying non-identical spreading codes, and multiple antennas are excited at the same time. This approach means that only a single FDTD simulation is needed whereas the conventional method needs as many simulations as there are transmitting antennas. A 2×2 multiple-antenna is simulated by way of a demonstration and it is found that the results of the proposed method agree well with those of the conventional method even though its computation time is shorter than that of the conventional method.

Keywords: FDTD, MIMO, array antenna, channel capacity, spread spectrum technique

Classification: Antennas and Propagation

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1 Introduction

Technologies for enhancing the data-rate in wireless communication are being actively pursued, and diversity antenna [1] and Multiple-Input Multiple-Output (MIMO) systems [2] are among the key technologies. The characteristics of the multiple antennas greatly impact the diversity gain and/or channel capacity. The effect of antenna characteristics on MIMO channel has been generalized by Wallace et al. [3], but the performance of a MIMO system strongly depends on the interaction between the antennas and the propagation characteristics. Therefore, evaluations of multiple antenna systems still need full simulations including the antennas and propagation environment. Unfortunately, this still incurs great computation cost even with recent progress in computers. Hence, a method that offers efficient MIMO channel simulations is needed.

The ray-tracing method [4, 5, 6] and the FDTD (Finite-Difference Time-Domain) method [7, 8] have been used for evaluating the propagation characteristics. Since the ray-tracing method is based on geometric optics theory, structures with a lot of detail cause an excessive increase in computation time or inadequate analysis accuracy. The FDTD method divides the analysis region into small cells, and Maxwell's equations are applied to explain the electromagnetic interactions among the cells. The FDTD method is convenient for analyzing detailed structures including antennas and propagation

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environments. For this reason, large scale analyses performed in recent years have used the FDTD method [8]. However, calculation time and memory increases in proportion to the total volume of analysis space.

A fast analysis method for multiple-antenna systems using OFDM (Orthogonal Frequency Division Multiplexing) pulse has been proposed [11]. This method enables the simultaneous analysis of multiple antennas since the excitation signals are spectrally orthogonalized (a benefit of OFDM modulation). However, this method cannot analyze two channels with the same frequency and which results in intermittent frequency response.

To resolve this drawback, this letter introduces the idea of the spread spectrum technique into FDTD analysis. The spectrum spreading codes for multiple transmitting antennas are made orthogonal to each other, and this enables the signals to be separated with high isolation at the receiving antennas [12]. That is, the multiple transmitting antennas are excited simultaneously and the MIMO channel can be calculated with just one single simulation. This letter describes in detail the proposed scheme and its mechanism. Numerical analysis results are also described; show that the proposed method offers much faster analysis than the FDTD method with conventional Gaussian pulse.

2 FDTD Analysis Using Spread Spectrum Technique

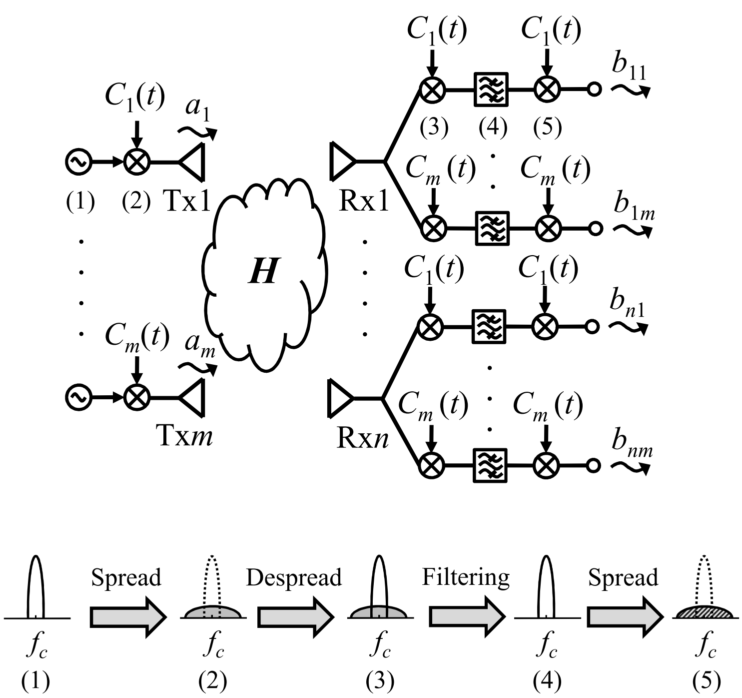

Fig. 1. The concept of the proposed method

Fig. 1 shows the concept of the proposed FDTD analysis method. In the conventional method, m transmitting antennas are excited independently, so m simulations are needed. In the proposed method, the signals for the multiple transmitting antennas are generated using non-identical spreading

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codes, and the multiple transmitting antennas are excited at the same time. At each receiving antenna, the mixed signals are multiplied by their respective spreading codes, and a band-pass filter extracts the desired signal. This is because the band-pass filter can remove the interference components. Finally, a spreading code is multiplied to this signal again because input signals are spread spectrum signal. These processes yield the input-output responses of all antennas, a_j, b_{ij} ($i = 1...n$, $j = 1...m$). The MIMO channel is given by $h_{ij} = b_{ij}/a_j$.

3 Numerical results

3.1 Analysis condition

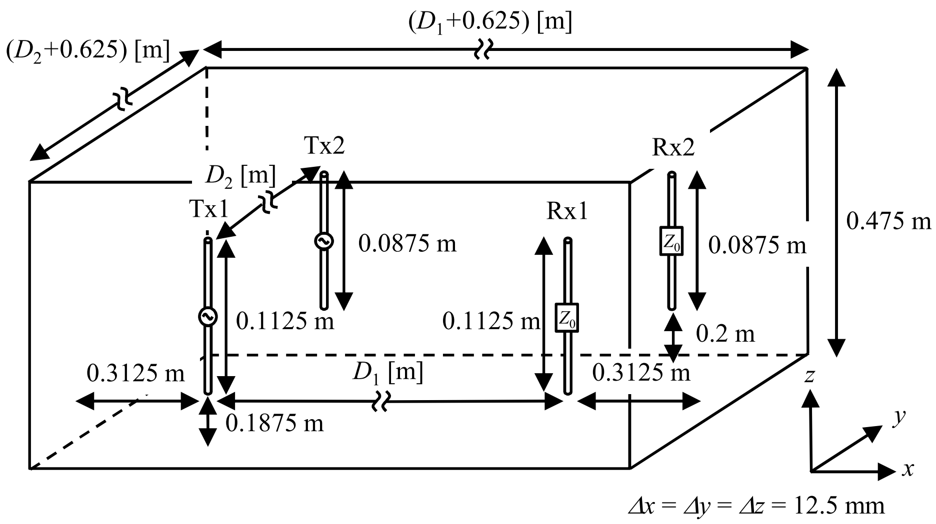

Fig. 2. Analysis model

The numerical analysis model of this study uses dipole arrays. The results obtained by the proposed method are compared to those of the conventional method. Fig. 2 shows the analysis model. The distance between the transmitting and receiving antennas is D_1 [m], and element spacing is D_2 [m]. Transmitting antennas are Tx1 $\sim$ Tx2, and receiving antennas are Rx1 $\sim$ Rx2. Element lengths are 0.1125 m for Tx1 and Rx1, and 0.0875 m for Tx2 and Rx2. Since we verify the analysis accuracy of the proposed method in this simulation, various Tx1 and Tx2 values are examined because we want to change the values of h_{11} and h_{22}. The distance between each element and the PML boundary condition is 0.3125 m. The cell size is 12.5 mm, and the delta gap model is used as the feeding model. PML boundary condition is employed for this calculation, and the number of PML layers is 8. The analysis frequency is 1.5 GHz, and the time step, Δt, is 24.07×10^{-12} s. Spread code is PN (Pseudorandom Noise) series, spreading code period is $T_c = 6.162\times10^{-9}$ s, and spreading code length is $T = 4.930\times10^{-8}$ s. Number of necessary time steps is N_{total}. When using Gaussian pulse, two individual analyses for two antennas are performed. In order to equalize the total calculation time, the number of time steps for Gaussian pulse is set to $N_{total}/2$.

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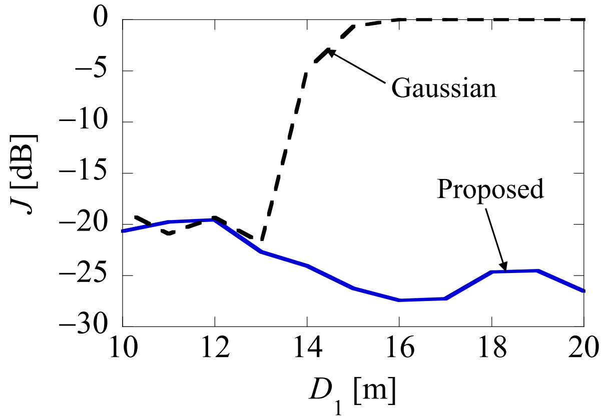
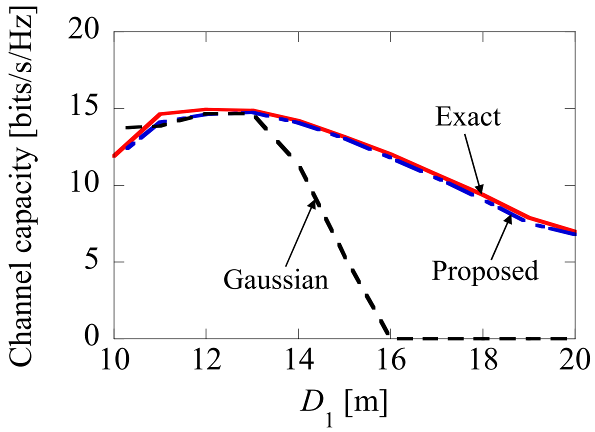


(a) Channel error versus propagation distance



(b) Channel capacity versus propagation distance

Fig. 3. Analysis results

3.2 Analysis results

Fig. 3 (a) plots channel error versus propagation distance. The channel error is defined as,

$$J = \frac{||\boldsymbol{H}^{ref} - \boldsymbol{H}||_F^2}{||\boldsymbol{H}^{ref}||_F^2}, \tag{1}$$

where, $\boldsymbol{H}$ is the propagation channel being evaluated and $\boldsymbol{H}^{ref}$ is the propagation channel created by the Gaussian pulse with sufficiently long time analysis (50000 time steps). N_t needs to be set so that the excitation signal reaches the receiving antenna, i.e.,

$$N_t = \frac{D_1}{v_c \Delta t}, \tag{2}$$

where v_c is the wave velocity in a vacuum; Δt is the time step. In the proposed method, a sliding correlator is used to detect the transmitted signal. Therefore, the number of time steps required for the analysis is expressed as,

$$N_{total} = \frac{D_1}{v_c \Delta t} + T + \alpha, \tag{3}$$

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where, T is the length of the excitation signal, α is the number of time steps required for sliding correlation. In this simulation, $T = 2048$ and $\alpha = 100$ time steps. Transmission power is 0 dBm, noise power is -80 dBm, and element spacing, D_2, is 2 m. The antenna spacing, D_1, is changed from 10 m to 20 m. The results in Fig. 3 (a) show that the greater the propagation distance between the antennas becomes, the larger the channel errors become in the conventional method. The reason is the propagation time between the transmitting and receiving antennas. Since the transmitted signal from one antenna cannot reach another antenna, the channel cannot be calculated correctly. On the other hand, the proposed method can analyze two-element antennas with a single FDTD simulation, and it is clear that the channel can be accurately analyzed in N_{total} time steps. This is because the antenna spacing, D_1, satisfies (3).

Fig. 3 (b) plots channel capacity versus propagation distance. 'Exact' shows the channel capacity obtained by long calculations (50000 time steps) with the Gaussian pulse. The channel capacities obtained by the proposed method agree very well with the exact result. However, a large error occurred in the results for the Gaussian pulse with $N_{total}/2$ time steps. Therefore, it is found that the proposed method can analyze MIMO channels with less computation time than the conventional method.

4 Conclusion

This letter presented a fast FDTD analysis method for multiple-antenna systems that use the spread spectrum technique. Spread spectrum codes maintain orthogonality among the excited signals. Simulations showed that the proposed method yields channel capacities that agree well with those of the conventional method even though the computation time is shorter than that of the conventional method. The results demonstrated that our analysis method is effective in reducing the computation time of FDTD analysis of multiple-antenna systems. As a final remark, the proposed method can be applied to antenna arrays that have more than 2×2 antennas.

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