NUMERICAL SIMULATION FOR MIMO WIRELESS CHANNEL BY USING HYBRID METHOD OF FDTD AND MoM

XiaoPeng YANG, Kenji YAMAGUCHI, Qiang CHEN, and Kunio SAWAYA

Electrical and Communication Engineering, Graduate School of Engineering, Tohoku University
05 Aza-aoba, Aramaki, Aoba-ku, 980-8579 Sendai, Japan   yang@sawaya.ecei.tohoku.ac.jp

1. Introduction

The performance of Multiple-Input Multiple-Output (MIMO) system using multiple antennas at both the transmitter and the receiver is affected significantly by the wireless propagation channel. Most of the researches on MIMO systems were investigating the channel loss and the channel correlation by using the signal processing technique according to the channel models such as the one-ring, the two-ring and the scattering disc models [1], and the accurate properties of the transmitting and receiving antennas and the realistic propagation channel have not been considered.

In this paper, a hybrid method for simulation of the MIMO wireless channel is proposed by combing the finite difference time domain (FDTD) method and the method of moment (MoM), which can be used to analyze a more realistic model for the MIMO systems with consideration of the properties of antenna elements and the propagation channel when the receiving array antenna are moving. Based on the evaluated channel transfer matrix obtained by this method, the channel capacities of the MIMO system are shown by changing the received signal to noise ratio (SNR), the number of antenna elements and the scatterers, and the array spacing to demonstrate the validity of the hybrid method.

2. Simulation method

2.1 Simulation model of MIMO system

The simulation model of the MIMO system is illustrated in Fig. 1. At the transmitter, the signal is divided into N_t independent sub-streams which are delivered separately to the N_t transmitting antennas. After multipath propagation, these sub-streams are received by N_r element array antennas, estimated by the maximum likelihood detection (MLD) method and merged to recover the original signal. The thermal noise is added at the input of the filters at the receiver. The received SNR is defined by the averaged power ratio of the received signal to the noise at each receiving antenna branch.

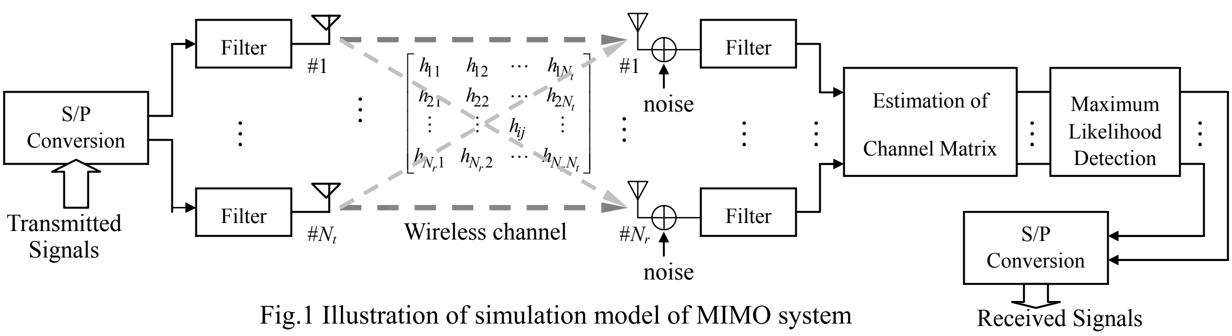

Fig.1 Illustration of simulation model of MIMO system

The error vector between the transmitted signal and the received signal is expressed as

$$e(t) = X(t) - \hat{X}(t) = \sum_{j=1}^{N_t} s_j(t) h_j + n(t) - \sum_{i=1}^{N_t} S_i(t) \hat{h}_i \qquad (1)$$

where $X(t) = [x_1(t), \cdots, x_{N_r}(t)]^T$, $S(t) = [s_1(t), \cdots, s_{N_t}(t)]^T$, $H = [h_1, \cdots, h_{N_t}]$ and $n(t)$ denote the received

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signal, the transmitted signal, the channel transfer matrix and the noise, respectively. The $\hat{h}_i$ is the element of the estimated channel transfer matrix $\hat{H}=[\hat{h}_1,\cdots,\hat{h}_{N_t}]$ including the effects of noise. The optimal estimate value of $\hat{H}$ can be obtained from the pilot signal $\bar{S}_j(t)$ by using the minimum mean square error (MMSE) method [2] as

$$\hat{H} = R_{XS}R_{SS}^{-1} \qquad \text{and} \quad R_{XS} = E\left[X(t)\bar{S}^H(t)\right],\ \ R_{SS} = E\left[\bar{S}(t)\bar{S}^H(t)\right] \qquad (2)$$

Based on the estimated value of $\hat{H}$, the original signal is recovered by using the maximum likelihood detection (MLD) method [3]. By comparing the estimated signal and the transmitted signals, the bit error rate (BER) of the MIMO system can be evaluated. Furthermore, the MIMO channel capacity can be calculated by [4]

$$C = \log_2\left[\det\left(I_{N_r} + \frac{\rho}{N_t}HH^+\right)\right] \quad \text{[bps/Hz]} \qquad (3)$$

where the channel transfer matrix H is calculated by the hybrid method when the noise is not added to the received signals.

2.2 Hybrid method of FDTD and MoM

The analysis model of the MIMO wireless channel using the hybrid method of FDTD method and MoM is shown in Fig.2. The FDTD method is used to analyze the transmitting antennas and the propagation channel, which can give an accurate solution of the received signals in the presence of conducting and dielectric scatterers with almost arbitrary structures and locations. When the receiving array antenna is moving, the FDTD analysis has to be repeated for all receiving points which are usually more than 10^4 so that the FDTD costs too much CPU time. This problem can be solved by using the hybrid method of the FDTD and the MoM. The electric field at every Yee cell inside the moving area of the receiving antenna is calculated by using FDTD in which the receiving antenna is removed from the FDTD analysis. Then, the MoM is applied to analyze the receiving array antenna to calculate the received signals at every receiving point. In the MoM analysis, the values of the electric field obtained by FDTD are used to evaluate the incident field on the receiving antenna. When the antennas move, only the incident electric field changes and there is no need to inverse the impedance matrix every time in the MoM analysis. Thus, the required CPU time of MoM can be significantly reduced. The Richmond's MoM is applied to the analysis of received signals where the sinusoidal function is used as the basis function and the weighting function [5].

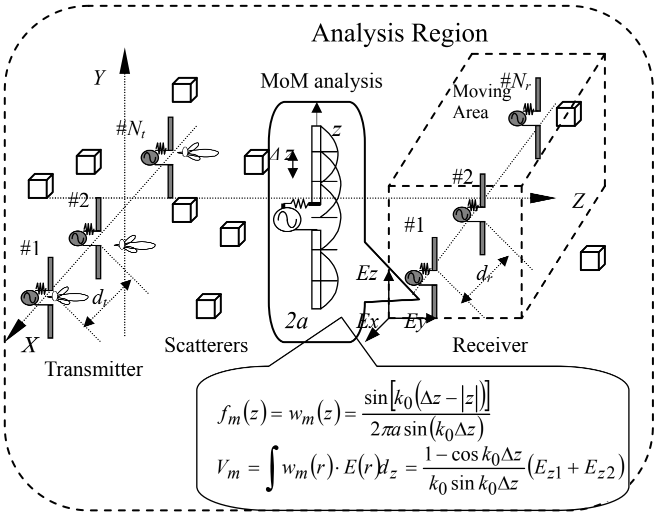

Fig.2 Wireless channel model with the hybrid method of FDTD and MoM

3. Simulation results

In the simulation, a vertical half wavelength dipole array antenna is used as the transmitting and the receiving antennas. The scatterers with number of N_S are conducting cubes whose side is a half wavelength and randomly located in the propagation channel. The transmitting antennas are fixed, while the receiving antennas move inside several wavelengths of the receiving area when receiving the data. The total transmitted power is fixed regardless of N_t, the uniform power allocation to the transmitting antennas is used. The region of FDTD analysis is divided into the Yee cells of 301×701×150 and each cell has a size of 1cm×1cm×1cm. The transmitted signal is modulated with BPSK and the carrier frequency is 1.5 GHz. Based on the evaluated channel transfer matrix by the proposed method, the channel capacities of MIMO system are calculated and compared.

The averaged MIMO channel capacity versus the received SNR is illustrated in Fig. 3 by using the proposed method with changing the number of scatterers N_S, $d_t=d_r=\lambda/2$ and $N_t=N_r=4$. Fig. 4 shows the channel capacity when the receiving array antenna is fixed. Comparing Fig. 3 and Fig. 4, it is clear that the proposed hybrid method can analyze the statistical characteristics of the MIMO wireless channel. The CPU time of the proposed method is much shorter than that of the FDTD method.

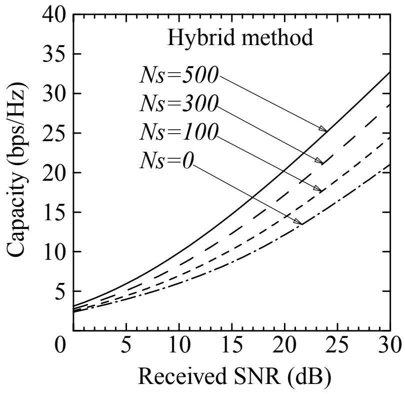

Fig. 3 MIMO capacity versus received SNR and number of scatterers when receiving antennas move by using proposed hybrid method. ($d_t=d_r=\lambda/2$, $N_t=N_r=4$)

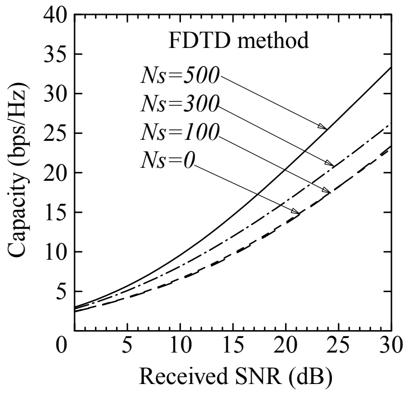

Fig. 4 MIMO capacity versus received SNR and number of scatterers when receiving antennas is fixed by using FDTD method only. ($d_t=d_r=\lambda/2$, $N_t=N_r=4$)

In the conventional wireless communication systems, a direct line of sight (LOS) transmission channel is desirable. On the other hand, the channel capacity can be improved by increase of the number of the scatterers in the MIMO wireless channels. This phenomenon is due to the fact that the channel correlation decreases and consequently the eigenvalues of HH^+ become large when the number of scatterers increases. The rich multipath environment makes almost perfectly orthogonal channel each other. Therefore, no direct line of sight (NLOS) in the wireless channel is necessary for the MIMO system to obtain the high channel capacity.

The MIMO channel capacity with changing N_t and N_r obtained by using the proposed method is illustrated in Fig. 5 when the number of N_S is 500, and $d_t=d_r=\lambda/2$. The ergodic MIMO capacity of the independent and identically distributed (i.i.d.) Rayleigh fading channels versus the received SNR with changing N_t and N_r is shown in Fig.6, the capacity expression of this case can be obtained in [6].

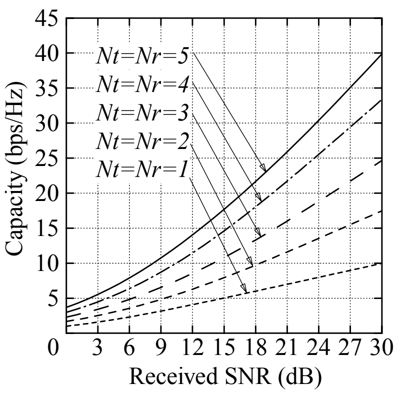

Fig. 5 MIMO capacity when $N_t=N_r$=1, 2, 3, 4, and 5. ($Ns=500$, $d_t=d_r=\lambda/2$)

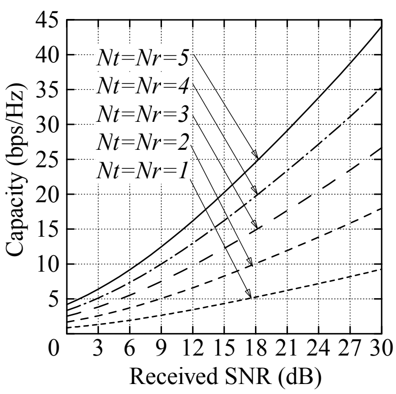

Fig.6 Ergodic capacity of i.i.d. Rayleigh fading MIMO channels when $N_t=N_r$=1, 2, 3, 4, and 5.

As the received SNR, N_t and N_r increase, the MIMO channel capacity increases. The MIMO capacity can increase almost linearly with the number of antenna elements when the received SNR is large.

According to the Shannon theorem, the capacity increases 1 bps/Hz for each 3dB increase in received SNR for the single antenna system. In the MIMO system, the capacity could increases $min(N_t, N_r)$ bps/Hz for each 3dB increase in received SNR as shown in Fig.5. The tendency of the simulated MIMO channel capacities agree with that of the theoretical results has demonstrated that the proposed hybrid method is valid to calculate the channel transfer matrix for the MIMO system. Although the MIMO capacity increases as N_t and N_r increase, the BER of MIMO system become worse when N_t and N_r increase as shown in Fig.7.

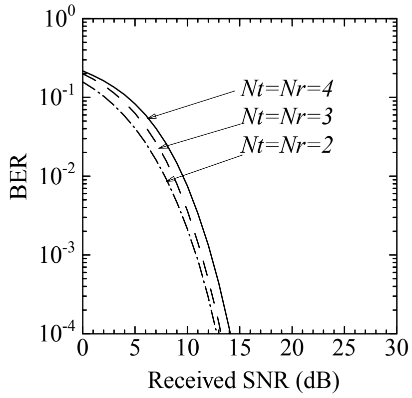

Fig. 7 BER versus the number of antenna elements (*Ns=500,* $d_t=d_r=\lambda/2$)

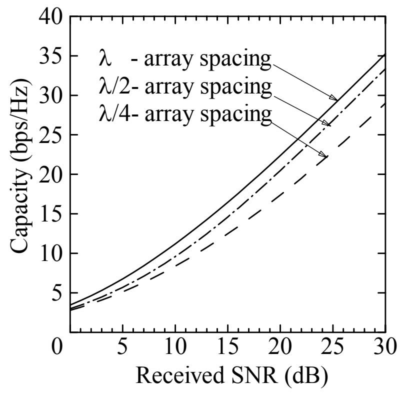

Fig. 8 MIMO capacity versus the array spacing (*Nt=Nr=4, Ns=500*)

The MIMO channel capacity versus the array spacing of transmitting and receiving antenna is shown in Fig. 8. The MIMO capacity decreases when the array spacing decreases because the orthogonality between the wireless channels becomes worse due to the increase of the mutual coupling between the array elements and the increase of the correlation between the different paths. This figure indicates that the degradation is obvious when the array spacing is less than $\lambda/2$.

4. Conclusion

A hybrid method for simulation of the MIMO wireless channel has been proposed by combing the FDTD method and the MoM with consideration of the properties of the practical antenna geometry and realistic propagation channel when the receiving array antenna moves. The channel capacities and BER of MIMO system are calculated and compared demonstrating the validity of the present method. The proposed method can provide some useful information to the design of practical MIMO system.

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