Channel Capacity for Various Materials of Partitions in Indoor Ultra Wideband Communication System with Multiple Input Multiple Output

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***Abstract*-In this paper, an image based ray-tracing model is used to calculate the channel capacity for various materials of partitions in indoor ultra wideband (UWB) system with multiple input multiple output (MIMO). The material parameters of the partitions such as dielectric constant and conductivity are both dependent on operation frequency in our calculations for more precise results. The effects of various materials of partitions on 2X2 MIMO UWB system are simulated for different signal-to-noise ratio (SNR).**

Ⅰ. INTRODUCTION

UWB is a promising radio technology for wireless communication and it can deliver very high data rates between short ranges [1], [2]. One of the reasons is that the bandwidth of UWB is very huge (from 3.1 to 10.6GHz), which is allocated by Federal Communications Commission (FCC) [3]. Since the channel capacity is proportion to bandwidth by Shannon's formula, the channel capacity of UWB is very large. The channel capacity is an important parameter that can be used for determining tradeoff of wireless communication system. Many studies about channel capacity of UWB have been published, including AWGN channel and multi-path channel [4]-[6].

MIMO transmission for wireless communications in rich multi-path environment has spectral efficiencies far beyond those offered by conventional techniques. Also the bandwidth efficiencies of MIMO transmission are better than conventional techniques [7], [8].

Channel capacity of UWB transmission and MIMO transmission has been discussed separately in many literatures. However, there are only a few papers dealing with MIMO UWB transmission [9], [10]. The UWB is a good transmission technology for future Wireless Personal Network (WPN), and the MIMO can be used to increase channel capacity and transmission quality. Combination of the two technologies can improve the spectrum efficiency.

Saleh-Valenzuela (S-V) statistical approach is a very general multi-path channel model for UWB system. It can be used to simulate four different scenes, including line of sight (LOS) and non LOS [11]. But the S-V model is not enough for more realistic environments compared to ray-tracing model. Some literatures about UWB system using ray-tracing model have been published [12], [13] and some MIMO system using ray-tracing have been published [14], [15].

In this paper, we use an image based ray-tracing model to calculate channel capacity for various materials of partitions in indoor MIMO UWB system. The material parameters of the partitions such as dielectric constant and conductivity are both dependent on operation frequency in our calculations for more precise results [16]. The effects of various materials of partitions on 2X2 MIMO UWB system are simulated for different SNR. This paper is organized as follows. Section Ⅱ introduces the simulation architecture for indoor MIMO UWB system. Section Ⅲ we calculate channel capacities and outage probability for various materials of partitions. Section Ⅳ presents numerical results and their comparison with the simulation. Section Ⅴ draws a conclusion.

Ⅱ. SIMULATION ARCHITETURE

A 3D image based ray-tracing model is used to MIMO UWB system for our simulation. We can build an environment and then calculate the frequency response between transmitter and receiver by using the model. We calculate the frequency response from 3.0 to 10.0 GHz with step 5MHz for satisfying bandwidth of UWB. The top view of our simulation environment is shown in Fig. 1.

There are two rooms in our simulation environment, which has a partition between them. The dimensions of each room are 5.5m (length) × 5.5m (width) × 3m (height). The partition has dimensions of 5.5m (length) × 0.2m (width) × 3m (height). The transmitter Tx (2.75m, 2.75m, 0.8m) is located on the center of the Room A. One hundred receivers are located in the Room B with uniform distribution.

The space between adjacent antennas is 0.15m, which is satisfying minimum space (λmax/2) without interference between adjacent antennas. Note that the maximum wavelength ($\lambda_{\max}$) is 0.1m in our simulation.

Seven materials of partitions will be considered in our simulation, including brick block, concrete block, drywall, close office partition, plywood, structure wood and Styrofoam. The dielectric constants and conductivities of the seven materials are both dependent on operation frequency.

The maximum bounces is chosen to four and maximum transmission (penetration) is chosen to one, because of we only considering Propagation effects in Room B and the effects are too small for our results with more bounces and transmission. The antennas of transmitter and receiver are both y-axis polarizations.

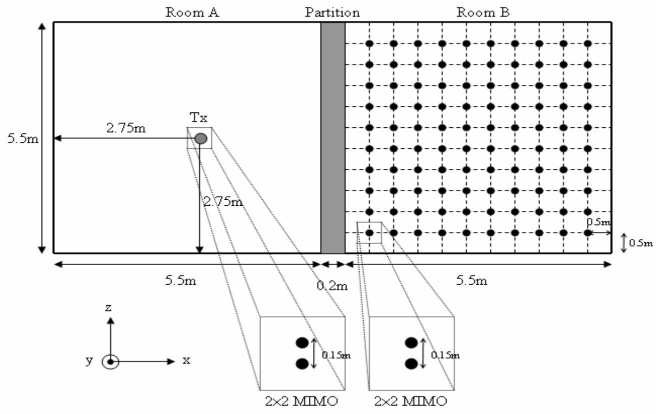

Fig. 1 Top view of the simulation environment

Ⅲ. CALCULATIONS OF CHANNEL CAPACITY AND OUTAGE PROBABILITY

A. Channel Capacity of MIMO system for Narrowband

A narrowband time-invariant wireless channel with n_t transmitter and n_r receiver antennas can be described by an n_r by n_t deterministic matrix H. And the received signal is described by

$$Y = HX + W \tag{1}$$

where $Y \in \Re^{n_r}$, $X \in \Re^{n_t}$, $W \in \Re^{n_r}$ denote the received signal, transmitted signal and zero mean white Gaussian noise respectively at a symbol time.

The capacity of the matrix H can be computed by decomposing the channel into a set of parallel and independent scalar Gaussian sub-channels by basic linear algebra. The matrix H can be expressed by singular value decomposition (SVD):

$$H = E\Lambda F^* \tag{2}$$

where $E \in \Re^{n_r \times n_r}$, $F^* \in \Re^{n_t \times n_t}$ are unitary matrix, and $\Lambda \in \Re^{n_r \times n_t}$ is a rectangular matrix whose diagonal elements are non-negative real values and other elements are zero.

A MIMO system is capable of signal processing at the transmitter and receiver to produce the set of received signals with highest overall capacity. If we define

$$\hat{\mathrm{X}} = \mathrm{F}^* \cdot \mathrm{X} \tag{3}$$

$$\hat{\mathrm{Y}} = \mathrm{E}^* \cdot \mathrm{Y} \tag{4}$$

$$\hat{\mathrm{W}} = \mathrm{E}^* \cdot W \tag{5}$$

then we can rewrite the equation (1) as:

$$\hat{Y} = \Lambda\hat{X} + \hat{W} \quad (6)$$

Because the unitary matrices don't change the geometrical length of vectors, so we aren't adding any power to the total transmitted signal. Thus, the energy is preserved and we have an equivalent representation as a parallel Gaussian channel:

$$Y_i = \lambda \times X_i + W_i \quad i = 1,2,...,n_{\min} \quad (7)$$

which $n_{\min} := \min(n_t, n_r)$. The equivalence is summarized in Fig. 2.

Now, the channel capacity of MIMO system for narrowband can be calculated as:

$$C^{narrowband} = \sum_{i=1}^{n_{\min}} \log_2 (1 + \frac{\lambda_i^2 P_i}{n_{\min} N_o}) \quad \text{bits/sec/Hz} \quad (8)$$

which P_i is receiving power from *i*th sub-channel and N_o is power spectrum density of AWGN. If we assume that the transmitter has excites each separate channel with equal power. Then the equation (8) can be rewritten as:

$$C^{narrowband} = \sum_{i=1}^{n_{\min}} \log_2 (1 + \lambda_i^2 \times \frac{SNR_r}{n_{\min}}) \quad \text{bits/sec/Hz} \quad (9)$$

which SNR_r is the receiving power to noise power ratio at each receiver antenna.

B. *Channel Capacity of MIMO system for UWB*

Through the ray-tracing model, we can get all the frequency response between any transmitter and receiver antennas from 3.0 to 10.0 GHz with step 5MHz. then we can get MIMO channel matrix $H_{MIMO-UWB}$, which has been normalized by the value H_{normal}.

$$H_{normal} = \sqrt{\frac{1}{n_t \times n_r \times n_f} \sum_{i=1}^{n_t} \sum_{j=1}^{n_r} \sum_{k=1}^{n_f} \left(|h_{ijk}|^2 \right)} \quad (10)$$

where h_{ijk} is the element of the channel transfer matrix for *k*th discrete frequency point, n_t and n_r are the number of transmit and receive antennas and $n_f = 1401$ is the number of discrete frequency points.

The UWB channel capacity can be calculate as summation of many channel capacities of narrowband at each discrete frequency point. Thus, the UWB channel capacity can be written as:

$$C^{UWB} = \frac{1}{BW} \sum_{k=1}^{n_f} C_k^{narrowband} \times \Delta f \quad \text{bits/sec/Hz}$$

$$= \frac{1}{BW} \sum_{k=1}^{n_f} \sum_{i=1}^{n_{\min}} \log_2 \{1 + [(\frac{SNR_t}{n_{\min}} \times H_{normal}{}^2) \times \lambda_{i,k}^2]\} \times \Delta f \quad (11)$$

which $BW = 7GHz$ is the using bandwidth of our simulation and $\Delta f = 5MHz$ is the frequency step. The SNR_t is defined as transmitting power to noise power ratio and $\lambda_{i,k}^2$ are the singular values of the normalized channel matrix $H_{MIMO-UWB}$ for *k*th discrete frequency point.

C. *Outage Probability*

In the practical communication systems, it is important to investigate the channel capacity in the sense of outage probability. An outage probability is defined as the event that the communication channel does not support a target data rate. If we give a data rate R, then the outage probability can be written as:

$$P_o = \mathrm{P}\{\mathrm{C}^{\mathrm{UWB}} < \mathrm{R}\} \quad (12)$$

Based on the above discussion, we can calculate the channel capacity and outage probability for MIMO UWB system in indoor environment.

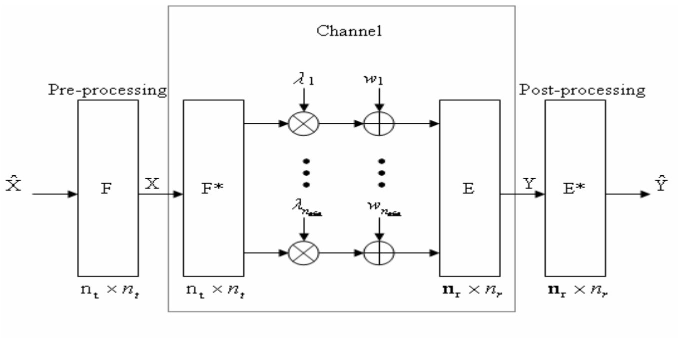

Fig. 2 Equivalent architecture of MIMO channel through the SVD

Ⅳ. NUMERICAL RESULTS

In this section, UWB frequency responses of a realistic environment for seven materials of partitions are simulated. The channel capacity and outage probability are then calculated.

We compare the effects of seven materials of partitions on 2X2 MIMO UWB system for different SNR_t. The numerical results are shown in Fig. 3 – Fig. 7, which SNR_t is 25dB, 30dB, 35dB, 40dB and 45dB, respectively. The average SNR_r is SNR_t subtracting 35dB and their value is about -10dB, -5dB, 0dB, 5dB and 10dB, respectively. We define a parameter R_m for determining criterion, which is the maximum transmission rate of MIMO UWB system when outage probability is zero.

In these figures, it is found that the value of R_m will increase when SNR_t increase for all the materials of partitions. The results can also be found form equation (9) and (10). Furthermore, we can find that the value of R_m of the seven materials of partitions are Styrofoam > drywall > close office partition > structure wood > brick block > concrete block > plywood for each SNR_t defined. The phenomenon can also be observed from conductivities of these materials. The conductivities of Styrofoam and drywall are both smaller than the others so that the propagation losses are both lower than the others. The differences between Styrofoam and plywood are about 1.0653, 2.1407, 3.5176, 5.0653 and 6.8744 for 25dB, 30dB, 35dB, 40dB and 45dB, respectively. All of above results are also listed in the TABLE.1.

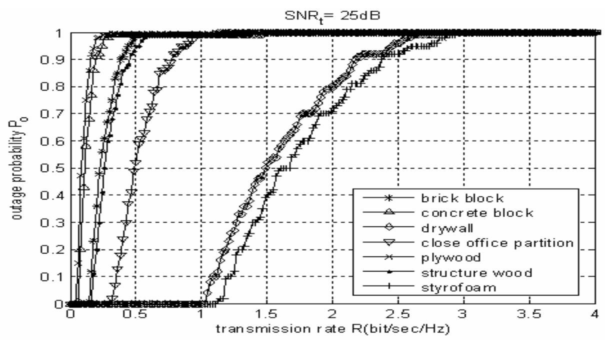

Fig. 3 Outage probability versus transmission rate for seven materials of partitions on 2X2 MIMO UWB system when SNR_t is 25dB

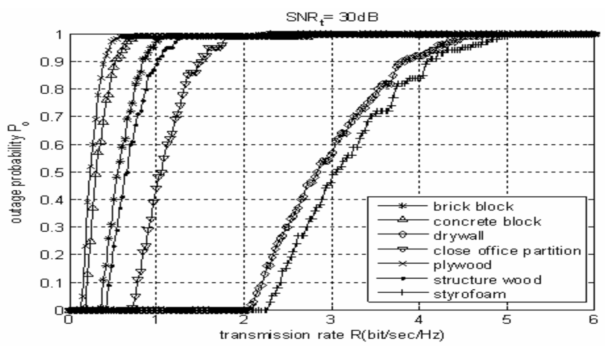

Fig. 4 Outage probability versus transmission rate for seven materials of partitions on 2X2 MIMO UWB system when SNR_t is 30dB

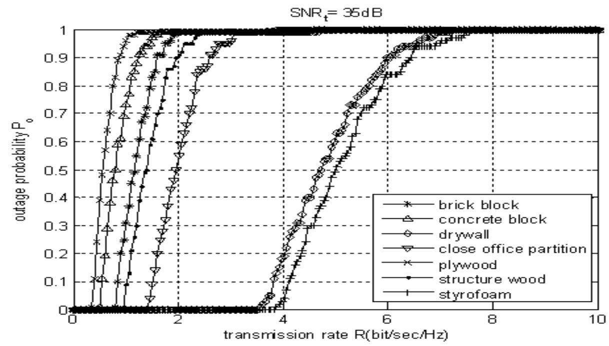

Fig. 5 Outage probability versus transmission rate for seven materials of partitions on 2X2 MIMO UWB system when SNR_t is 35dB

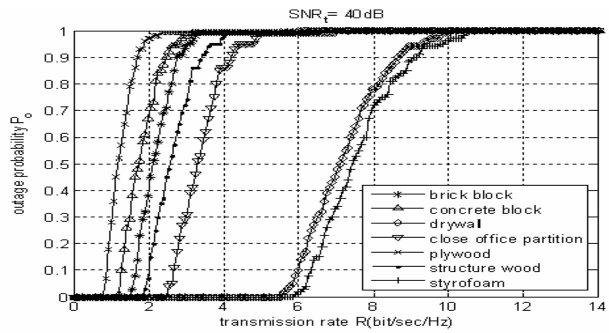

Fig. 6 Outage probability versus transmission rate for seven materials of partitions on 2X2 MIMO UWB system when SNR_t is 40dB

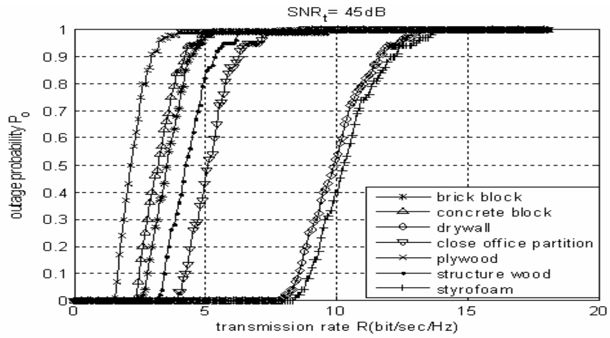

Fig. 7 Outage probability versus transmission rate for seven materials of partitions on 2X2 MIMO UWB system when SNR_t is 45dB

TABLE. 1 The maximum transmission rate (bits/sec/Hz) for seven materials of partitions on 2X2 MIMO for each SNR_t when outage probability is zero

	Maximum transmission rate (bits/sec/Hz)				
Materials	SNR_t =25dB	SNR_t =30dB	SNR_t =35dB	SNR_t =40dB	SNR_t=45dB
brick block	0.12	0.33	0.75	1.48	2.53
concrete block	0.04	0.15	0.45	1.13	2.26
drywall	1.03	2.05	3.52	5.49	7.87
close office partition	0.30	0.69	1.41	2.46	3.89
plywood	0.04	0.12	0.30	0.77	1.45
structure wood	0.14	0.39	0.90	1.83	3.17
Styrofoam	1.11	2.26	3.82	5.84	8.32

V. CONCLUSIONS

A method for analyzing and calculating the channel capacity for various materials of partitions in indoor 2X2 MIMO UWB communication system has been presented by ray-tracing model. A realistic environment is simulated in this paper. Moreover, the frequency dependence of materials utilized in the structure on the indoor channel is accounted for in the channel simulations. i.e., the dielectric constant and conductivity of objects are not assumed to be frequency independent.

Numerical results show that the partition of Styrofoam has largest maximum transmission rate, and the partition of plywood has smallest one. It is also seen that the transmission rate R_m will increase when SNR_t increase for all the materials of partitions.

Finally, our research provides a deterministic data about the maximum transmission rate for different materials of partitions. The data can be used for determining transmission rate of wireless communication system by a given outage probability.

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