DETERMINISTIC MIMO CAHNNEL ANALYSIS METHOD USING RAY-TRACING PROPAGATION MODEL

Sang-Hoon Oh and Noh-Hoon Myung
Div. of Electrical Eng., Dept. of Electrical Eng. & Computer Science,
Korea Advanced Institute of Science and Technology
373-1, Guseoung-dong, Yuseong-gu, Daejeon, 305-701, Korea
E-mail: zeros@eeinfo.kaist.ac.kr, nhmyung@ee.kaist.ac.kr

1. Introduction

MIMO (Multiple-Input Multiple-Output) systems can increase the channel capacity without the expansion of bandwidth in multipath-rich environment, and so have been investigated for next generation wireless communications. MIMO systems adopt multiple antennas at both tx./rx. ends, and if sub-channels on each antenna element pair are i.i.d., the total channel capacity increases linearly with the number of antenna element. As in practical case, however, if sub-channels are correlated with each others, the rate of increase is bent. Therefore, the information about MIMO channel matrix is needed to estimate MIMO channel capacity. Many models representing MIMO channel have been published by now, but they assume simple scenarios and Rayleigh fading channel, and estimate the capacity statistically, so can not consider specific propagation environment. This paper makes an analysis of MIMO channel using ray-tracing as deterministic approach to specific environment. This method can make site/orientation specific channel analysis, and based on EM theory, can consider various electric properties of walls of buildings and antennas. In addition, it shows high efficiency for time and cost, not by measurements nor Monte-Carlo simulations.

2. Channel Analysis Method

The MIMO channel capacity expression by [Foschini '96] is for random process, so a closed-form expression is needed for deterministic channel analysis by the ray-tracing propagation model. Using Jensen's inequality and concavity of '*log det*', an upper bound of mean capacity at receive ends, $\overline{C}_R$, can be obtained, as following [2]:

$$E[C] \leq \overline{C}_R = \log_2\left(\det\left[\mathbf{I}_{N_R} + \frac{\rho}{N_T} E\left[\mathbf{H}\mathbf{H}^*\right]\right]\right) \quad (1)$$

where N_T, N_R is the number of the transmit/receive antenna elements, respectively, $\mathbf{H}$ is $N_R \times N_T$ normalized channel matrix, $\mathbf{I}_{N_R}$ is $N_R \times N_T$ identity matrix, and ρ is the averaged SNR (signal-to-noise ratio). If $E\left[\mathbf{H}\mathbf{H}^*\right] = \mathbf{R}^r$ is defined, the entries of the correlation matrix, $\mathbf{R}^r$, can be expressed [2] as $r_{ij}^R = \sum_{k=1}^{N_T} E\left[h_{ik} h_{jk}^*\right]$, where h_{ij} is sub-channel impulse response between the *j*-th transmit and the *i*-th receive antenna element. This equation considers only the correlation of receive branches, and when the correlation of transmit branches is considered, $E\left[\mathbf{H}^*\mathbf{H}\right] = \mathbf{R}^t$, $\overline{C}_T$ can be also obtained, alternately. Finally, by taking the minimum of the two bounds, the upper bound near to the mean capacity can be estimated [2].

For the estimation of the correlation between sub-channels, the discrete spatial correlation method is used [3]. The fading of received signals is mainly caused by the movement of receive antenna, and therefore, assuming the ergodicity of received signals, we can estimate the envelope correlation by spatial samplings instead of time averaging [3]. By the discrete samplings of received fields in the sampling area (shown in Fig.1), the correlation between two signals (v_1, v_2) is defined, as followings:

ISBN: 89-86522-77-2 94460©KEES

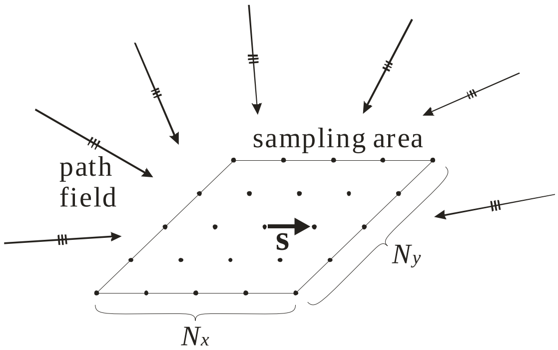

Fig. 1. sampling area and positioning vector

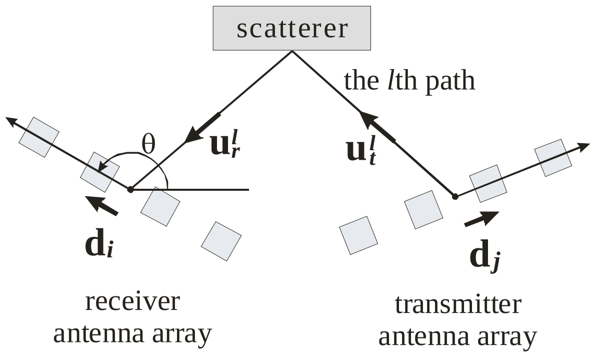

Fig. 2. definition of vector parameters on the *l*-th path

$$\hat{R}(v_1, v_2) = \frac{\sum_{i=1}^{N_x}\sum_{j=1}^{N_y}\{v_1(i,j)-\bar{v}_1\}\cdot\{v_2(i,j)-\bar{v}_2\}}{\sqrt{\left(\sum_{i=1}^{N_x}\sum_{j=1}^{N_y}\{v_1(i,j)-\bar{v}_1\}^2\right)\cdot\left(\sum_{i=1}^{N_x}\sum_{j=1}^{N_y}\{v_2(i,j)-\bar{v}_2\}^2\right)}}$$

$$\bar{v}_m = \frac{1}{N_x N_y}\sum_{i=1}^{N_x}\sum_{j=1}^{N_y} v_m(i,j) \quad , \quad v_m(i,j) = \sum_{l=1}^{L} p_l \cdot \exp\{-2\pi j\cdot(\mathbf{u}_r^l \cdot \mathbf{s}_{ij})\} \tag{2}$$

where p_l is the field of the *l*-th path, $\mathbf{u}_r^l$ is the unit direction vector of the *l*-th path (shown in Fig.2), and $\mathbf{s}_{ij}$ is the sampling position vector from the element centre point to the sampling point. Assuming that the distance from scatterers to antennas is very far compared with the scale of antenna arrays, the amplitude of each path field is constant and only the phase is changed due to sampling positions. In this case, the ray-tracing is performed only between the centre points of transmit/receive arrays, and so computation time is reduced. The field of the *l*-th path of sub-channel h_{ij} can be represented as following:

$$p_{ij}^l = A_{ij}^l \exp\{-2\pi j\cdot(\mathbf{u}_r^l\cdot\mathbf{d}_i)\}\exp\{2\pi j\cdot(\mathbf{u}_t^l\cdot\mathbf{d}_j)\} \tag{3}$$

where A_{ij}^l is the field of the *l*-th path considering the pattern and polarization of the *i*-th receive antenna element and the *j*-th transmit antenna element. It is multiplied by the phase difference term due to the position of each antenna element. $\mathbf{d}_i, \mathbf{d}_j$ are position vectors of the *i*-th receive and the *j*-th transmit antenna element from the center of arrays, respectively (shown in Fig. 2). Each sub-channel h_{ij} has *L* pathes in common, but the phase of each path varies with the sub-channel, so each channel has different fading with each other.

Analysis process is accomplished in reverse order of the contents described above. First, using the imported building data, ray-tracing is performed between the centre points of the transmit/receive antenna arrays (by [1]). and then each sub-channel h_{ij} has the path list respectively considering the strength changes by the electric properties and the phase changes by position of the corresponding transmit/receive antenna element. Next, the discrete spatial correlation between each sub-channels is computed, and by this, $\mathbf{R}^r$, $\mathbf{R}^t$ and $\overline{C}_R$, $\overline{C}_T$ is obtained successively. Finally, by taking the minimum of $\overline{C}_R$ and $\overline{C}_T$, the upper bound of the MIMO channel mean capacity is estimated.

3. Analysis Results

For the verification of MIMO channel analysis method described above, the simulation results are compared with the correlation measurement data in Villa Griffone from reference [4]. Half wavelength dipoles were used for both tx./rx. antennas at 900MHz. The tx. antenna was located on the first floor, but the rx. antenna moved along several routes on the second floor. More detail description of the measurement system and environment is written in [4]. Fig. 3. shows a comparison between measured and simulated data of the spatial correlation averaged over entire routes versus rx. antenna element spacing. The measured and simulated

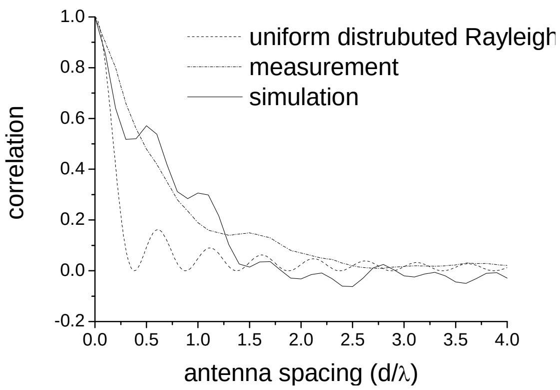

Fig. 3. averaged correlation between two rx. antenna element in Griffone building

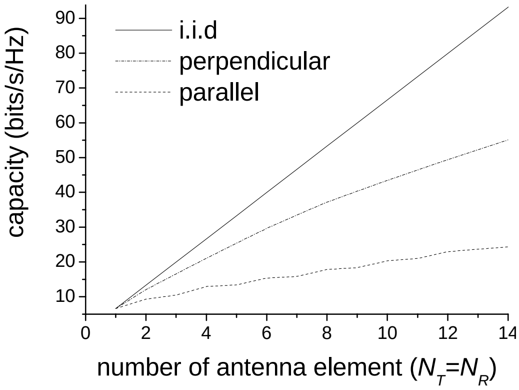

Fig. 4. capacity changes by antenna array orientation in the LOS region

correlations are always higher than the theoretical ones assuming Rayleigh-fading channel with uniform AOA (angle-of-arrival), and it is because, in practical environment, there is no case which received pathes uniformly distributed over all direction, while dominant path having stronger signal strength than others always exist.

For the examination of capacity variation by propagation environment, we compared the measurement data in Clyde building from [5] with the simulated data. The tx./rx. antennas have ten dipoles forming a uniform circular array at 2.43GHz, and elements spacing is 0.5 wavelength. More detail description of the measurement system and environment is presented in [5]. The measurements of MIMO channel mean capacity are performed over three routes (route1~route3), and these data are compared with the simulated data in Fig 5~7, respectively. In LOS (Line-of-Sight) region, the SNR arises greatly and a deviation of this value is large, and so the channel capacity has a tendency similar with the SNR graph. For the test for the capacity variation by multipath richness instead of the SNR, the capacity for the case the SNR is set to 10dB over the entire routes, is shown in (c) of each Fig. 5~7. In LOS, it is conformed that the correlation increases and the channel capacity decreases by existence of the dominant pathes. The reason the simulated values are higher than the measured is because the calculated results are the upper bound of the mean channel capacity [3]. However, a relative tendency can be informed by this way, and so performance test according to various propagation environment and antenna structure is possible.

The rectangular marks in Fig. 5~7 present the results which the vertical/horizontal polarization is applied alternately to each antenna elements. In the case applying dual polarization antennas which have been used for diversity efficiency, the SNR decreases a little, but the correlation decreases remarkably, so it has a good influence on the channel capacity. This circular array antenna is little affected on the performance by the orientation, but linear array is heavily affected by the orientation, especially in LOS region. Fig. 4 shows a result of the calculated channel capacity by antenna array orientation versus the number of antenna element of the linear antenna array. The case which the antenna array is perpendicular to the LOS shows better performance than the parallel case, and it is because if propagation pathes converge into one direction and the deviation of the AOA is not large, the case of the perpendicular array to the LOS generates a phase difference on each element the most sensitively by a little AOA changes. (by (2) $\because \cos'(\theta)|_{\theta\sim 90^\circ} > \cos'(\theta)|_{\theta\sim 0^\circ}$) The simulation results for the correlation variations by the antenna orientation are shown in [5].

4. Conclusion

This paper presents the method of estimating the MIMO channel characteristics deterministically using the ray-tracing propagation model. This method is not by measurements, so that can reduce the cost and time for the channel analysis, and if the channel holds the ergodicity,

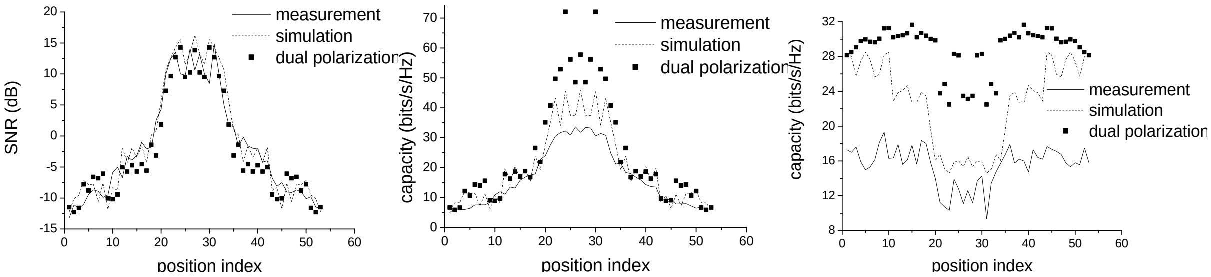

Fig. 5. (a) SNR, (b) capacity, (c) capacity normalized by SNR=10dB, along route 1 in Clyde building

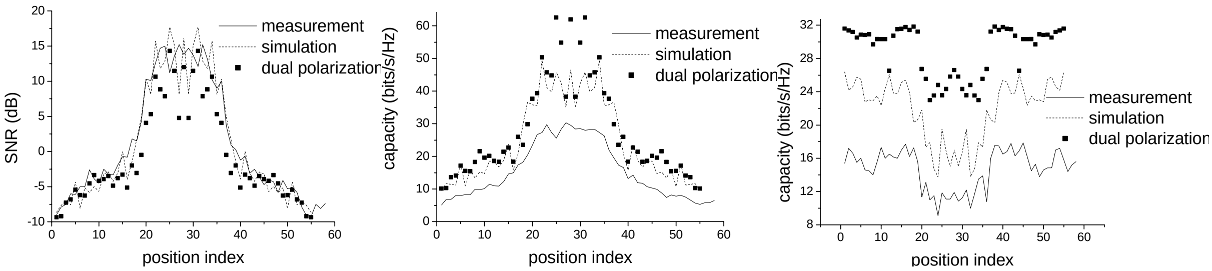

Fig. 6. (a) SNR, (b) capacity, (c) capacity normalized by SNR=10dB, along route 2 in Clyde building

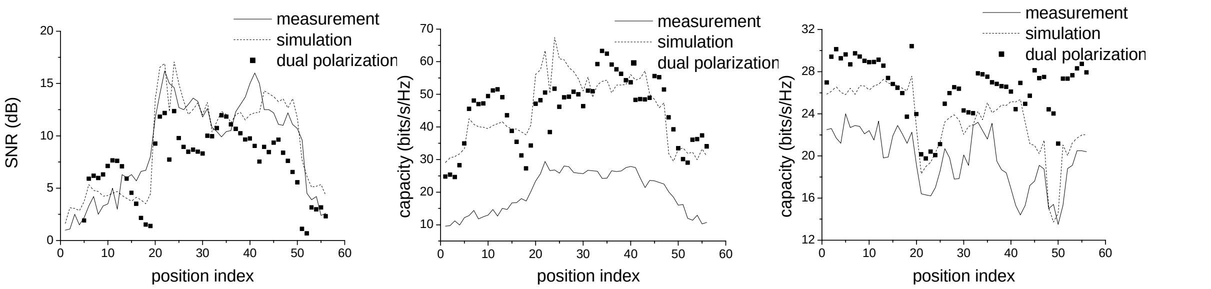

Fig. 7. (a) SNR, (b) capacity, (c) capacity normalized by SNR=10dB, along route 3 in Clyde building

it can estimate the relative trend of the correlation and capacity by comparatively simple computations, not by Monte-Carlo simulations. It is supposed that the MIMO channel characteristics are affected strongly by the position and orientation of antennas, and by this method, the site-specific and orientation-specific channel analysis is possible. This method is based on the EM theory, so that the quantitative analysis for various propagation parameters – electric properties of buildings and pattern, polarization, structure, mutual coupling of antennas, and so on - which can affect the system performance is also possible. Therefore, it is expected to be helpful for the development of antenna structure suitable for MIMO systems.

Acknowledgement : This work was supported by the KOSEF through MICROS and ADD through RDRC center at KAIST, and EMERC at Chungnam National Univ.

Reference :

1. H. W. Son and N. H. Myung, "A Deterministic Ray Tube Method for Microcellular Wave Propagation Prediction Model," *IEEE Transactions on Antennas and Propagation*, Aug. 1999, 47, (8)
2. S. Loyka and A. Kouki, "On the Use of Jensen's Inequality for MIMO Channel Capacity Estimation," *Electrical and Computer Engineering, 2001. Canadian Conference on*, May 2001, 1, pp. 13-16
3. G. E. Corazza, V. Degli-Esposti, M. Frullone, and G. Riva, "A Characterization of Indoor Space and Frequency Diversity by Ray-Tracing Modeling," *IEEE Journal on Selected Areas in Communications*, April 1996, 14, (3)
4. T. Svantesson and J. Wallace, "On Signal Strength and Multipath Richness in Multi-Input Multi-Output Systems," *Communications, ICC '03. IEEE International Conference on*, 11-15 May 2003.
5. S. H. Oh and N. H. Myung, "MIMO Channel Estimation Method Using Ray-tracing Propagation Model," *IEE Electronics Letters*, Vol. 40, No. 21, Oct. 2004.