Experimental Evaluation of Indoor MIMO Channel Capacity Based on Ray Tracing

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Abstract: In a more realistic indoor environment we demonstrate the use of the ray tracing method to predict the capacity of a multiple input multiple output(MIMO) indoor wireless communication systems. The channel response for 4 by 4 MIMO systems located inside an office environment operating at 5.2 GHz is constructed by using Wireless InSite, ray tracing simulation tool. The uniform linear array(ULA) and 3D array of vertical dipoles are investigated to estimated MIMO capacity. The results are in a good agreement with those reported by the IEEE indoor MIMO WLAN channel model.

1 Introduction

MIMO systems have attracted a considerable interest as a practical approach to achieve significant increases in wireless channel capacity. Theoretical investigations have revealed significant improvements in throughput for a fading environment when multiple transmitter and receiver antennas are deployed [1]. Similar results are presented in [2] for Gaussian channels in environments with and without fading. Some research work uses stochastic channel models to evaluate the MIMO capacity and bandwidth efficiency [3]. A ray tracing approach is used in [4] to estimate the capacity of a MIMO wireless system with an objective of clarifying the general principles involved in MIMO indoor channels, rather than accurately determining channel capacities for a specific system. Moreover, the theoretic capacity evaluation of MIMO system based on site specific ray tracing using a uniform linear array of vertical dipoles with half wavelength has been reported in [5].

In this paper, the capacity of indoor MIMO channels in a more realistic propagation environment are investigated by using a ray tracing tool known as Wireless InSite [6]. A single user case with 4 transmitting and receiving antennas is considered and the channel response for multiple antennas in an office environment has been characterised. Not only the uniform linear array(ULA) of vertical dipoles is investigated in this scenario, but a 3D array is taken into amount, which is more practical for antenna design.

This paper is organized as follows: Section II reviews the channel model and MIMO capacity. In Section III, the basic assumptions for the capacity simulation using Wireless InSite is described. The results are presented and validated in Section III as well. Finally, some general conclusions are drawn regarding the capacity of indoor channel, and 3D array of antenna elements.

2 Channel Model and Capacities

We consider a single user communication system with N_T antennas that transmits independent data streams which are received by N_R antennas($N_T = N_R = n$). For a narrowband system in which the communication bandwidth is assumed to be narrow enough that the Fourier transform of channel impulse response appears constant over the frequency band of interest, the N_R received baseband signals r are related to the N_T transmitted signals s as

$$r = Hs + v \tag{1}$$

where H is a $N_R \times N_T$ matrix that describes the channel. The element H_{ij} represents the complex path gain from transmitter j to receiver i, for $i = 1, 2...$ and $j = 1, 2...$; s is a $n \times 1$ signal vector whose j^{th} component represents signal sent by j^{th} antenna; vector r and v are $n \times 1$ received signal and additive noise, respectively.

The channel capacity of a narrowband (n, n)MIMO system, assuming there is no channel state information at transmitter and the total transmit power is equally allocated to all n antennas, has been derived in [1] as:

$$C(\xi) = \log_2 \det [I_n + \frac{\xi}{n} \cdot HH^\dagger] \quad bits/Hz \tag{2}$$

where ξ donates the average signal-to-noise ratio at each receiver; $H^\dagger$ for Hermitian transpose of H; det for determinant, and I_n for identity matrix. H is the normalized $n \times n$ channel matrix, that is $\sum_{j=1}^{n} |h_{ij}|^2 = 1$. Also we assume a flat channel, that is one non-frequency selective.

Applying singular value decomposition to H, we can obtain a pair of unitary matrices U and V such that:

$$H = UDV^\dagger \tag{3}$$

where $U \in C^{n \times n}$ and $V \in C^{n \times n}$. D is diagonal and its entries are the non-negative square roots of the eigenvalues of $HH^\dagger$, λ_i for $i = 1, 2...n$, Equation (2) becomes:

$$C(\xi) = \log_2 \det [I_n + \frac{\xi}{n} \cdot D^2] = \sum_{i=1}^{n} \log_2 [1 + \frac{\xi}{n} \cdot \lambda_i] \tag{4}$$

3 Numerical Results and Validation

Wireless InSite[6] is used to evaluate the channel matrix in our simulation study. The channel response is modelled as the vector sum of all the rays arriving at the receiving antenna locations. A narrowband channel is assumed in this study. The frequency response at infinitesimally small bandwidth centred at the carrier frequency can be computed by the following equation, which is modified from [7]:

$$h_{ij} = \sum_{k=1}^{M} \sqrt{P_k} \cdot e^{i(2\pi/\lambda) l_k} \cdot e^{i 2\pi f_0 \tau_k} \tag{5}$$

where M is the number of rays, f_0 is the carrier frequency,P_k is the received power, l_k is the length of the k^{th} ray and τ_k is the time delay of the k^{th} ray. H is computed using equation (5) and P_k, l_k and τ_k are obtained from Wireless InSite simulations.

A propagation model for a 4 by 4 MIMO system operating in the second floor of the electronic engineering building(Figure 1) of Queen Mary, University of London is modeled in Wireless InSite. Four vertical dipoles are considered, which are firstly arranged in linear array with a

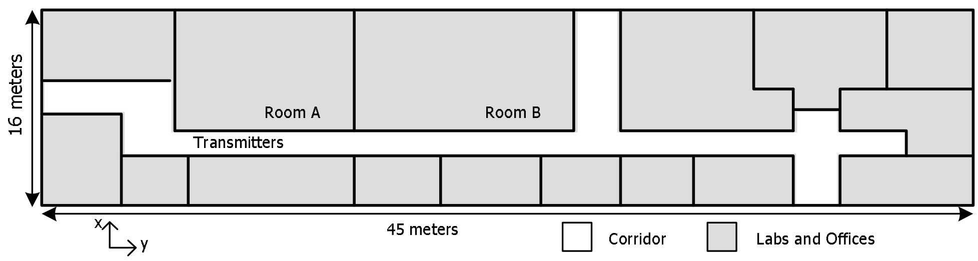


Figure 1: Floor Plan for the second floor of Department of Electronic Engineering at Queen Mary, University of London. Receivers with 4 antennas are located randomly at 1000 positions in Room A and B, respectively.

$3\lambda \times 1\lambda \times 2\lambda$ box, then in a 3D dimension with the same dimension box, where λ is the carrier wavelength, depicted in Figure 2(a) and Figure 2(b). Four transmitter antennas are placed on the ceiling of the corridor outside room A. The receiver antennas were located in 1000 positions at desk-top height in room A, and B. Room A is close to the transmitter compared to room B. The corresponding H was calculated.

(a) (b)

Figure 2: Configurations for the receiving antennas, (a) ULA wiht equal spacing = $\lambda/2$ between dipoles, and (b) 3D array arrangement.

Further, the linear array configuration for the receiving dipoles is investigated in room A, where the spacing between dipoles is $\lambda/2$. Our ray tracing(RT) model uses the same parameters and similar environment with IEEE 802.11 MIMO channel model to run the simulations, which are listed in Table 1 below.

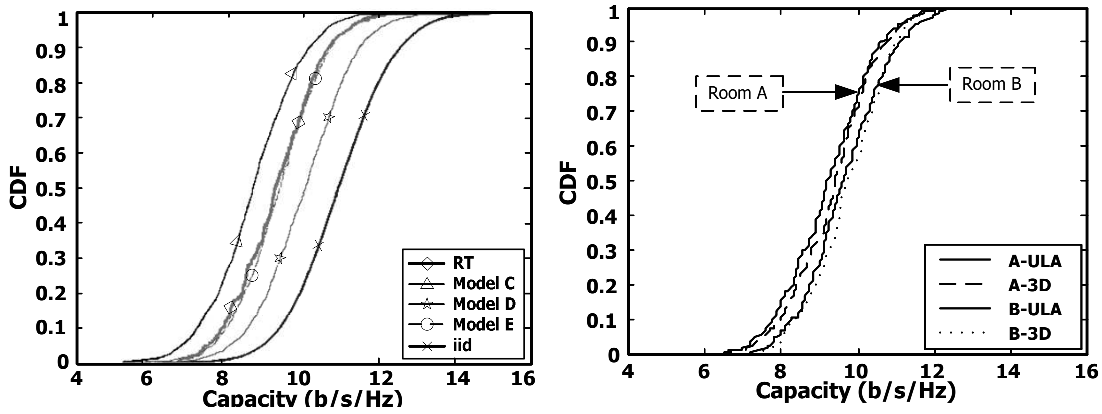
	802.11 MIMO Model[8]	**RT Model**
Environments	Model C, D and E with NLOS for small office, typical office and Large office, respectively.	Offices of Department of Electronic Engineering at Queen Mary.
Simulation Parameters	4×4 set-up Uniform linear array(ULA) $\lambda/2$ adjacent antenna spacing Isotropic antennas No antenna coupling effect All antennas with same polarization(Vertical)	

Table 1: Parameters for IEEE 802.11 model and RT model

The cumulative distribution functions (CDFs) of narrowband capacity for the RT model, IEEE Model C,D and E including the iid case (channel matrix elements are independent and identically distributed zero-mean unit-variance complex Gaussian random variables) are plotted in Figure 3 with SNR $\xi = 10dB$, 1000 channel realizations, and NLOS conditions. It can been seen that the capacity result from the RT model is in a good agreement with Model E of IEEE indoor MIMO channel.

In the MIMO antenna design for mobile terminals, the 3D antenna array is more practical. For example, a four element diversity antenna array for a PDA terminal in 3D configuration was proposed in [9]. The parameters for this simulation are kept the same as the preceding one except the antenna arrangement, where the 3D antenna array depicted in Figure 2(b) is used. The capacity results for ULA and 3D antenna array in room A and B are demonstrated in Figure 3(b).

The solid curves in Figure 3(b) are capacities for ULA in room A and B, which agree very well with the IEEE MIMO model. The capacity in room B is slightly higher than that in room A, which is due to the presence of more scattering paths for the more distant and larger room B. The dotted curves in Figure 3(b) are the capacity with 3D antenna configuration in Room A and B. The most important thing is that the same capacity can be achieved in the 3D antenna array not only in room A but B, compared with the ULA antenna configuration.



(a) (b)

Figure 3: The illustration for the validation and capacity for the ULA and 3D antenna configurations, (a) Comparisons of RT MIMO model in Room A and IEEE MIMO models, and (b) Capacities for 3D and ULA in Room A and B.

4 Conclusion

We have evaluated the capacity of MIMO indoor wireless communication system operating at 5.2 GHz in an office environment. By using the Wireless InSite tool to evaluate the channel response, the capacity results for ULA antenna configuration has been validated by comparing with IEEE MIMO channel model. Using the validated ray tracing model has shown that high capacity is possible for the 3D antenna array configuration.

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