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PERFORMANCE OF BEAMFORMING AND MIMO TECHNIQUE IN AN INDOOR RICEAN CLUSTERING CHANNEL

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ABSTRACT

In this paper, we present a hybrid indoor MIMO channel model for predicting the performance of multiple-element antenna system. The model incorporates the wave clustering phenomena and combines the statistical characteristics of clusters with deterministic ray tracing method. The capacity of the MIMO channel is expressed as a function of spatial correlation at both the transmitter and the receiver. The results obtained by using the channel model are compared with measurement results available in the literature. Simulation results verify that the MIMO technique effectively exploits multipath fading. The paper also presents a comparison between MIMO and beamforming techniques in indoor environments.

KEY WORDS
MIMO, beamforming, indoor, clustering, Ricean channel.

1. Introduction

Smart antenna arrays that consist of multiple-element antennas (MEA) at the transmitter and receiver are being proposed as promising candidates for increasing the wireless spectrum efficiency. Beamforming and multiple-input multiple-output (MIMO) technique with Space-Time coding [1-4] are two different approaches used to improve the performance of wireless links that use MEA. Here, we use the term, MEA to refer to any wireless links that utilize multiple-element arrays at both the transmitter and receiver, inclusive of both beamforming and MIMO. The MIMO technique employs multiple antennas at the transmitter and receiver, and spectrum efficiency improvements are achieved through the establishment of spatial subchannels between the transmit and receive antennas. Beamforming, however, is a well known traditional smart antenna technique used to improve the performance of MEA system by reducing interference. Recently, there is an increased interest in the use of hybrid technique incorporating both MIMO and beamforming techniques. Therefore, a comparison between performance of MIMO and beamforming in different indoor environments is helpful for the design of any hybridized scheme.

In this paper, utilizing a hybrid MIMO channel model [5], the performance of the approaches in a Ricean indoor channel is investigated. It is found that beamforming can achieve comparable spectrum efficiencies to that of MIMO in different LOS scenarios.

2. Indoor Cluster MIMO Channel Model

The clustering phenomenon in an indoor channel has been observed both in measurements [6] and in ray tracing (RT) simulations [7]. A study on angle of arrival (AOA) in indoor environments using ray tracing and actual measurement reported by Wang, et al. [8] verified that the AOA information of incident clusters can be accurately obtained by the ray tracing technique. On this basis, a hybrid clustering indoor MIMO channel model, emphasizing the clustering of signals is proposed in [5]. The channel model combines both deterministic and statistical characteristics of signal clusters.

In a clustering indoor channel, the received signal is the sum of mutipath clustered signals and the LOS direct component

$$r = r_{los} + \sum_{i=1}^{N_s} r_i = r_{los} + \sum_{i=1}^{N_s}\sum_{l=1}^{N_i} r_{il} \qquad (1)$$

where N_s and N_i are the number of incident clusters and multipath components within the i^{th} cluster, r_i denotes the received signal induced by cluster i, which is a zero-mean Gaussian variable. In addition, r_{il} denotes the induced signal due to multipath component l within the i^{th} cluster; r_{los} denotes the induced signal due to LOS direct component.

The spatial cross correlation coefficient of received signals between two antenna elements with a spacing of

d is defined by $\rho(d) = E[r_1 r_2^*]$. The spatial correlation can be represented as:

$$\rho(d) = \frac{K}{K+1}\rho_{LOS}(d,\theta_{LOS}) + \frac{1}{K+1}E[\rho_i(d,\theta_i)] \qquad (2)$$

where ρ_{los} denotes the spatial correlation coefficient due to LOS component, $\rho_i(d,\theta_i)$ denotes the spatial cross correlation coefficient due to the i^{th} cluster with a mean AOA of θ_i, K is Ricean factor which is defined as the ratio between the signal power of LOS direct component and the signal power of NLOS components. In this model, both the AOA and the AOD of the LOS component and the NLOS clusters are obtained using the RT tool for a specified indoor environment. The correlation coefficient between two antenna elements due to the i^{th} cluster with mean AOA of θ_i, $\rho_i(d,\theta_i)$ is obtained as

$$\rho_i(d,\theta_i) = \int e^{-jkd\cos(\theta_i+\theta_{ij})} p(\theta_{ij}))d\theta_{ij} \qquad (3)$$

where θ_{ij} is the AOA of the j^{th} ray within the i^{th} cluster with respect to its mean AOA of θ_i, k is the wave number.

In this paper, we investigate the fading due to spatial effects rather than temporal effects. Hence the narrow band flat fading channel is assumed. Due to the reciprocal nature of indoor RF channels, the MIMO channel matrix H with P transmit and M receive antennas can be reconstructed as [9, 10] :

$$H = (R_R)^{1/2} G[(R_T)^{1/2}]^T \qquad (4)$$

and the MIMO channel capacity is computed using the formula given in [2]

$$C = \log_2(\det(I + \frac{\rho}{P}HH^*)) \qquad (5)$$

where G is a stochastic matrix with i.i.d elements, $(\cdot)^{1/2}$ represents any matrix square root, $(\cdot)^T$ denotes matrix transposition, R_R and R_T are the signal correlation matrices at the receiver and transmitter side, respectively. The elements of each can be obtained using equations (2) and (3). ρ is the desired SNR at each receive antenna. I is a identity matrix.

3. Performance of MEA in Indoor Clustering Ricean Channel

- **Validation of the Channel Model**

We validate our model by comparing with measurement results in terms of channel capacity. The model is applied to a classroom located in the 23rd floor of a 30-storey tower building at UTS. Both transmit and receive arrays are assumed to be at the same height of 1.7 meters above the floor to ensure that the waves are mainly (approximately) confined to the horizontal plane. The locations of the transmitter as well as the receiver within the horizontal plane have been varied as shown in Fig.1.

A comparison of our simulation results with measured capacity given by Li et al. in [11] for a 4x4 MIMO channel is shown in Fig.2. Our simulations were for a MIMO channel with a centre frequency of 5.4 GHz and an SNR of 20 dB. The physical arrangement is as shown in Fig.1. In the simulation, the angle spread of the Laplacian cluster is assumed to be 22° taken from published measurement results in [12], whereas the Ricean factor K is assumed to be 2 (3 dB). The interelement spacing of ULA is half a wavelength. Although the measurement environment in [17] is an indoor corridor, the existence of a wall at one end of the corridor makes it similar to our environment. A reasonable agreement of capacity can be found between measured data in [17] and our simulations.

- **Performance of Beamforming and MIMO**

Using singular value decomposition (SVD), the capacity when equal power allocation is used in equation (5) can be rewritten as:

$$C_{EP} = \sum_{i=1}^{m} \log_2(1 + \rho\lambda_i / P) \qquad (6)$$

where λ_i $i=1\cdot\cdot m$ ($m \le min(P,T)$) is the non-zero eigenvalues of R_H, $R_H = HH^*$.

When the channel state information is available at the transmitter and receiver, the capacity can be optimized by utilizing the waterfilling scheme. The resulting capacity is

$$C_{WF} = \sum_{i=1}^{m} \log_2 \det(1 + P_i\lambda_i / \sigma^2) \qquad (7)$$

where $\sum P_i = P_T$ and $P_i = (u - 1/\lambda_i)^+$, and $()^+$ denotes taking only those terms which are positive, μ is called the water level.

Beamforming, one of the conventional smart antenna techniques, has been used as a means to reduce the effects of both multipath and co-channel interference. Basically, the principle of beamforming is that by adding the received signal from each array element with an appropriate array weight, gains in signal power and a reduction in interference power can be achieved. Beamforming corresponds to using the principal eigenmode alone, and the channel capacity is given as:

$$C_{BF} = \log_2(1 + P_T\lambda_1 / \sigma^2) \qquad (8)$$

where λ_1 is the eigenvalue corresponding to the principal eigenmode.

Referring to Fig.1, we have chosen a scenario using a transmitter at T1 and a receiver at R1 (T1R1) with a 4-element array for comparison. The results are shown in Figs.3, 4 and 5. From the SNR point of view in Fig.3, in the low SNR range, beaforming can achieve comparable performances to that of the MIMO waterfilling which is, inturn, better than that of MIMO with equal power allocation. When the SNR is greater than 10 dB, beamforming loses its advantage. Fig.4 shows the performance of the above three schemes with different Ricean factors *K* and with constant *SNR=10 dB*. The Ricean factor *K* is negative for both the MIMO cases viz., equal power and waterfilling schemes. However, beamforming is not sensitive to the Ricean factor. The reason for this is that, whilst the MIMO scheme distributes power over all applicable spatial subchannels, beamforming puts all transmit power to the dominant LOS subchannel only. The result in Fig.5 verifies that the angular spread of clusters does not significantly influence either MIMO or beamforming.

4. Conclusions

Using an indoor channel model based on signal clustering, an investigation of performance of the MIMO technique and of beamforming in terms of spectrum efficiency is conducted. In a clustering correlated indoor environment, beamforming can achieve spectrum efficiencies as good as that obtainable with the MIMO waterfilling scheme in a certain SNR range. Due to the existence of the LOS component, beamforming always performs better in a wide range of environments with different Ricean factors. Our study suggests that beamforming is a good candidate scheme for MEA links in an indoor clustering LOS Ricean channel. We hope this investigation can provide useful insights for the development of future high performance indoor MEA communication systems.

5. Acknowledgements

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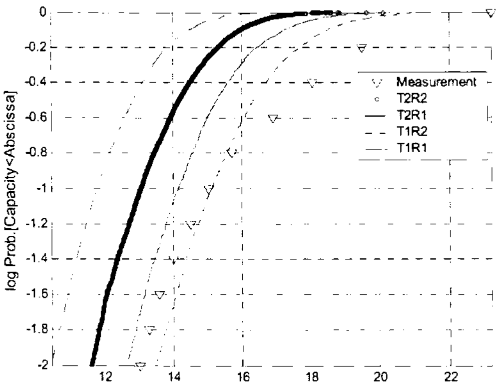

Fig.2. Comparison with measurement.

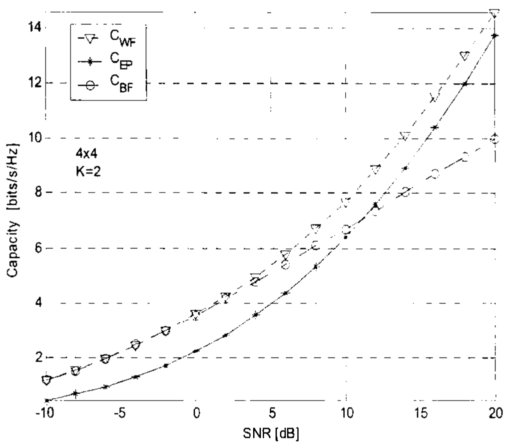

Fig.3. Effect of SNR on capacity.

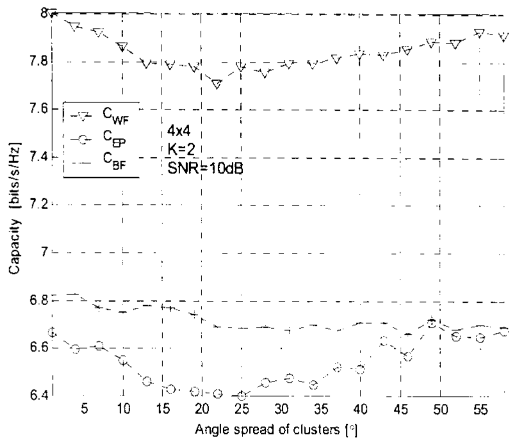

Fig.5 Effect of angle spread on capacity.

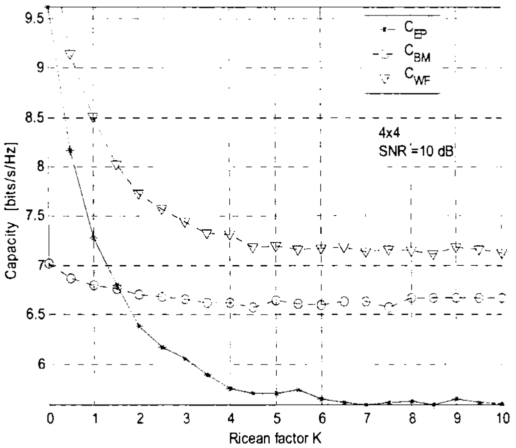

Fig.4. Effect of Ricean factor K on capacity.

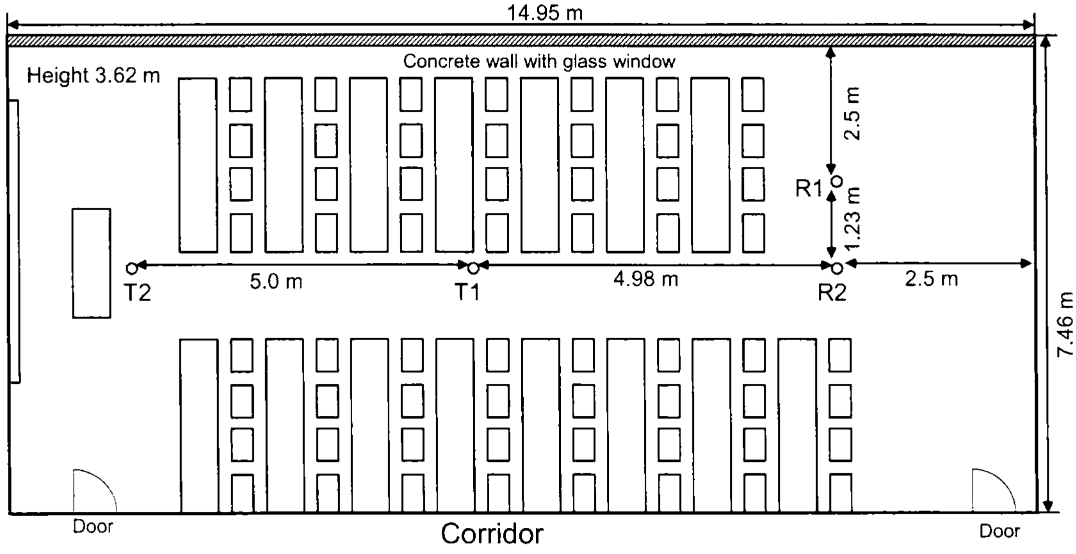

Fig.1. Ray tracing prediction for an indoor environment.