Correlation Properties and Capacity of Antenna Polarization Combinations for MIMO Radio Channel

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Abstract

This paper analyzes the MIMO (Multi-Input-Multi-Output) channel correlations under different antenna polarization combinations. Measurement results show that the horizontally-polarized combination is more correlated than vertically-polarized combination. And in the environment with rich scattering, there is no benefit to use cross-polarized combination to increase channel capacity. While in the environment without rich scattering, like in open space, the cross-polarized combination is an efficient way for enhancing channel capacity.

Introduction

The rapidly increasing need for high transmission rate in communication system motivate researchers to search for potential structures capable of achieving high spectral efficiency. MIMO system proposed by Foschini [1] is a well-known structure showing large capacity enhancement by parallel channeling. However, the capacity of an MIMO system is highly dependent on the correlation properties of the channels. Many reports [2] show that spatial correlation can be reduced by increasing element spacings. If compact antenna implementation is required, dual polarized antenna is a good choice to achieve similar performance [3].

This paper presents measured results performed in an indoor corridor and an outdoor open space. We consider polarization combinations. The measurement campaigns are under a 4×4 MIMO setup. The measured results for all setups will be compared in terms of power correlation and capacity.

Measurement Setup

Considering a two-array system in a scattering environment with M antenna elements in the base station(BS) and N antenna elements in the mobile station(MS). The narrowband two-array system (or MIMO system) can be represented as an $M\times N$ channel matrix $\mathbf{H}=[h_{mn}]$, where h_{mn} is the complex channel coefficient between the m^{th} antenna at the BS and the n^{th} antenna at the MS.

The MIMO measurements were performed with M=N=4. Two single-pole-four-throw(1P4T) switches are used at both MS and BS to simulate parallel transmission and receptions. CPW fed linearly polarized slot antennas centered at 1.9GHz were used. The element spacing is fixed to 1λ. To explore the diversity with different combinations of polarization, we set the antennas in three different ways. The first way is to place antennas both at MS and BS all vertically polarized. The second way is to place them all horizontally polarized. In the third way, antennas are placed so that they are horizontally or vertically polarized with neighboring ones orthogonal to each other. These antenna arrays are mounted 1.6 meters above the ground.

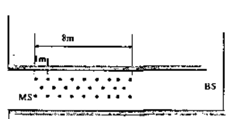

Fig.1 Indoor corridor

Environmental description

The following results are extracted from measurement campaigns undertaken in two different environments. The first environment is an indoor corridor as shown in Fig.2. The second environment is at an outdoor opening space with little reflections from building. The BS is fixed and for each environment, the MS are moved to many different locations where the Line-Of-Sight (LOS)

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component is always presented. Thus the channels are correlated in both cases, but the channels of the outdoor environment are more correlated. The circles shown in Fig.1 are locations of the MS.

Measured Results

Correlation Analysis

To maximize MIMO channel capacity, we need parallel uncorrelated subchannels. However, elements of the channel matrix **H** are usually correlated and the correlation coefficients depend on the angular spread of the incident multipath components. The main goal of the measurement campaigns is to evaluate the spatial correlations between elements of the same antenna array.

The correlation coefficients between antenna elements at the MS and the BS can be expressed by [4]

$$\rho^{BS}_{m_1 m_2} = \left\langle \left|h_{m_1 n}\right|^2, \left|h_{m_2 n}\right|^2 \right\rangle \qquad \rho^{MS}_{n_1 n_2} = \left\langle \left|h_{m n_1}\right|^2, \left|h_{m n_2}\right|^2 \right\rangle$$

where $\langle a, b \rangle$ denotes the correlation between (a, b) and is given by

$$\rho = \langle a, b \rangle = \frac{E[ab] - E[a]E[b]}{\sqrt{\left(E[a^2] - E[a]^2\right)\left(E[b^2] - E[b]^2\right)}} \qquad (1)$$

where $E[\cdot]$ denotes expectation. The spatial power correlation coefficient ρ^{power} is defined as:

$$\rho^{power} = |\rho|$$

Define the correlation matrix of the MS and BS as follows:

$$\mathbf{R}_{BS} = \begin{bmatrix} \rho^{BS}_{11} & \rho^{BS}_{12} & \cdots & \rho^{BS}_{1M} \\ \rho^{BS}_{21} & \ddots & & \vdots \\ \vdots & & \ddots & \vdots \\ \rho^{BS}_{M1} & \cdots & \cdots & \rho^{BS}_{MM} \end{bmatrix} \qquad \mathbf{R}_{MS} = \begin{bmatrix} \rho^{MS}_{11} & \rho^{MS}_{12} & \cdots & \rho^{MS}_{1N} \\ \rho^{MS}_{21} & \ddots & & \vdots \\ \vdots & & \ddots & \vdots \\ \rho^{MS}_{N1} & \cdots & \cdots & \rho^{MS}_{NN} \end{bmatrix}$$

The spatial power correlation coefficients at the MS and BS obtained by the above definitions for both environments and different antenna setups are given below:

Indoor corridor:

(1) VVVV case

$$\mathbf{R}_{BS} = \begin{bmatrix} 1 & 0.3898 & 0.1685 & 0.0865 \\ 0.3898 & 1 & 0.3114 & 0.0680 \\ 0.1685 & 0.3114 & 1 & 0.5857 \\ 0.0865 & 0.0680 & 0.5857 & 1 \end{bmatrix} \qquad \mathbf{R}_{MS} = \begin{bmatrix} 1 & 0.4400 & 0.1299 & 0.2207 \\ 0.4400 & 1 & 0.7064 & 0.0796 \\ 0.1299 & 0.7064 & 1 & 0.1203 \\ 0.2207 & 0.0796 & 0.1203 & 1 \end{bmatrix}$$

(2) HHHH case

$$\mathbf{R}_{BS} = \begin{bmatrix} 1 & 0.8174 & 0.5064 & 0.3746 \\ 0.8174 & 1 & 0.8151 & 0.6037 \\ 0.5064 & 0.8151 & 1 & 0.8929 \\ 0.3746 & 0.6037 & 0.8929 & 1 \end{bmatrix} \qquad \mathbf{R}_{MS} = \begin{bmatrix} 1 & 0.8929 & 0.7093 & 0.4528 \\ 0.8929 & 1 & 0.8490 & 0.5604 \\ 0.7093 & 0.8490 & 1 & 0.8036 \\ 0.4528 & 0.5604 & 0.8036 & 1 \end{bmatrix}$$

(3) VHVH case

$$\mathbf{R}_{BS} = \begin{bmatrix} 1 & 0.4333 & 0.2261 & 0.4235 \\ 0.4333 & 1 & 0.3369 & 0.7242 \\ 0.2261 & 0.3369 & 1 & 0.2919 \\ 0.4235 & 0.7242 & 0.2919 & 1 \end{bmatrix} \qquad \mathbf{R}_{MS} = \begin{bmatrix} 1 & 0.3942 & 0.3824 & 0.4057 \\ 0.3942 & 1 & 0.3634 & 0.6737 \\ 0.3824 & 0.3634 & 1 & 0.3490 \\ 0.4057 & 0.6737 & 0.3490 & 1 \end{bmatrix}$$

Outdoor open space:

(1) VVVV case

$$\mathbf{R}_{BS}=\begin{bmatrix}1 & 0.6614 & 0.7992 & 0.5576\\ 0.6614 & 1 & 0.6874 & 0.7916\\ 0.7992 & 0.6874 & 1 & 0.5912\\ 0.5576 & 0.7916 & 0.5912 & 1\end{bmatrix}\quad \mathbf{R}_{MS}=\begin{bmatrix}1 & 0.8840 & 0.7052 & 0.4534\\ 0.8840 & 1 & 0.7908 & 0.4745\\ 0.7052 & 0.7908 & 1 & 0.5727\\ 0.4534 & 0.4745 & 0.5727 & 1\end{bmatrix}$$

(2) HHHH case

$$\mathbf{R}_{BS}=\begin{bmatrix}1 & 0.8292 & 0.9148 & 0.8175\\ 0.8292 & 1 & 0.8666 & 0.6598\\ 0.9148 & 0.8666 & 1 & 0.8749\\ 0.8175 & 0.6598 & 0.8749 & 1\end{bmatrix}\quad \mathbf{R}_{MS}=\begin{bmatrix}1 & 0.9270 & 0.9114 & 0.8441\\ 0.9270 & 1 & 0.9446 & 0.8884\\ 0.9114 & 0.9446 & 1 & 0.9327\\ 0.8441 & 0.8884 & 0.9327 & 1\end{bmatrix}$$

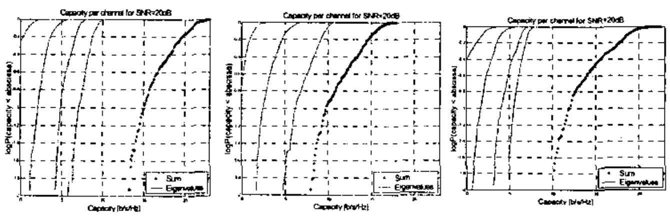
(3) VHVH case

$$\mathbf{R}_{BS}=\begin{bmatrix}1 & 0.6580 & 0.9348 & 0.6690\\ 0.6580 & 1 & 0.5861 & 0.9422\\ 0.9348 & 0.5861 & 1 & 0.6396\\ 0.6690 & 0.9422 & 0.6396 & 1\end{bmatrix}\quad \mathbf{R}_{MS}=\begin{bmatrix}1 & 0.5473 & 0.9510 & 0.5847\\ 0.5473 & 1 & 0.5677 & 0.9533\\ 0.9510 & 0.5677 & 1 & 0.6111\\ 0.5847 & 0.9533 & 0.6111 & 1\end{bmatrix}$$

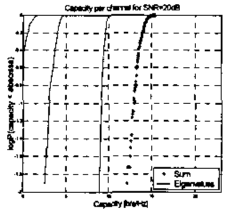
It is seen that in both environments, the horizontal polarization case has greater correlation coefficients than the other cases. While the correlation coefficients in the outdoor open space are greater than those in the indoor environment. In the outdoor case, the dominant paths are from the direct path and the ground reflections, and these two components almost have the same azimuthal angle. While in the indoor corridor, there are reflections from the walls, which results in greater angular spread and therefore smaller correlation coefficients. In the vertical polarization case, the direct path and the ground reflection component are destructively interfered, which makes the contribution of other components more important and therefore gives smaller Rician factor and smaller correlation coefficients. While in the horizontal polarization case, the direct path and the ground reflection component are constructively interfered. The contribution from other components becomes less important and results in larger Rician factor and greater correlation coefficients. It is surprised that in the cross-polarized case, the correlation coefficients between cross polarizations are not very small. Although the adjacent elements of the H matrices have very different magnitude due to the isolation between orthogonal polarizations, the correlation coefficients obtained by Eq.(1) are not necessary small.

Eigenanalysis

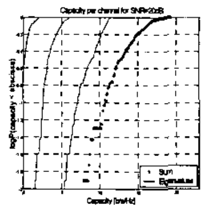
To evaluate the channel capacity of each MIMO system, we use Singular-Value-Decomposition (SVD) method to find the channel gain, and then use Shannon's capacity formula [5] to give the cumulative distribution function of the capacity of each subchannel. All channel matrices are normalized to the mean value of the SISO of the V-V polarization. The CDFs of capacities corresponding to different eigenvalues and the total capacity for different polarization combinations in both environments are shown below.



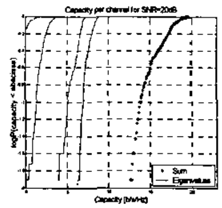
Indoor corridor VVVV case | Indoor corridor HHHH case | Indoor corridor VHVH case



Outdoor VVVV case



Outdoor HHHH case



Outdoor VHVH case

In the VHVH case, the isolation between the V-polarized element and the H-polarized element makes half number of the H-matrix elements having small amplitude. Therefore, in the scattering rich environment, the eigenvalue of the VHVH case is smaller than that of VVVV case, which results in the channel capacity of the VHVH combination in the corridor environment being smaller than that of the VVVV combination. However, in the open space case, the strong correlation between antenna elements makes the co-polarized combinations have one large eigenvalue and small for all other eigenvalues. While in the VHVH combinations, the isolation between the V- and H-polarized elements makes the amplitude difference between eigenvalues much smaller, which results in a higher total capacity as shown in the figures of the outdoor case.

Conclusion

In this paper we have compared the MIMO correlation coefficient properties and channel capacity for different polarization combinations in the indoor corridor and outdoor open space environments. It was found that the horizontally-polarized elements are more spatially correlated than the vertically-polarized elements. In the environment with rich scattering, the cross-polarized combination will loose channel gains to obtain independent receptions which are already in existence and result in lower capacity, while in the environment without rich scattering, the cross-polarized combination is an efficient way for enhancing channel capacity.

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