Two Element Arrays of Circular Patch Antennas in Indoor Clustered MIMO Channels

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Abstract

In this paper we analyze a multiple input multiple output (MIMO) array consisting of two circular microstrip antennas, designed to exploit pattern diversity. The two circular microstrip elements are collocated and stacked upon each other. The spatial correlation coefficients of this array as a function of the mode excited, for realistic clustered MIMO channel models are derived. The angle of arrival/angle of departure are distributed only over the azimuth direction is the assumption taken for circular patch array (CPA) and the performance is compared against an array of two spaced dipoles with the help of the simulation results. Simulation tool used is MATLAB 7.4.

Keywords : Pattern Diversity, Circular Patch Antenna(CPA), Uniform Linear Array(ULA)

1.Introduction

MIMO technology has attracted attention in wireless communications, since it offers significant increases in data throughput and link range without additional bandwidth or transmit power. MIMO wireless systems use multiple antenna elements at transmit and receive to offer improved capacity over single antenna topologies in multipath channels [1]. In such systems, the antenna channel characteristics play a key role in determining communication performance. The capacity and reliability of MIMO wireless communication systems may be sensitive to the design of the antenna arrays employed at the transmitter and receiver, as well as to the nature of the propagation between the arrays. It has been shown that the capacity of a MIMO system increases linearly with the number of antennas in the presence of a scattering-rich environment [2]. This will ensure that the signals at the antennas in the array are sufficiently uncorrelated with each other [3]. This is where antenna design comes in for MIMO systems.

The throughput that a multiple-input multiple-output (MIMO) channel can support depends on element spacing [4]-[6], array geometry [4],[7],[8], radiation pattern, cross-polarization and the spatial characteristics of the propagation environment (i.e., angle spread, angle of arrival, power angle profile). MIMO antenna arrays can be designed to reduce the channel spatial correlation, resulting in enhanced link performance.

One way to reduce the spatial correlation is to space the antennas far apart by exploiting space diversity. Depending on the spatial characteristics of the MIMO channel, the distance between the array elements needs to be multiple of the wavelength to ensure good system performance. In typical MIMO systems, size and cost constraints often prevent the antennas from being placed far apart. Therefore, space diversity techniques may be insufficient for next generation wireless handsets. One promising solution to overcome the size limitations of wireless devices is pattern diversity. To exploit pattern diversity, the antennas are designed to radiate with

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orthogonal radiation patterns as a means to create uncorrelated channels across different array elements [9].

We analyze a MIMO array consisting of collocated circular microstrip antennas. This MIMO array exploits pattern diversity without requiring excessive real estate for spacing the antennas. Different modes can be excited inside the microstrip, yielding different capacity/error rate performance. We consider two element arrays, where the antennas have the same polarization, to isolate the effect of pattern from polarization diversity [10]-[13]. This paper is organized as follows. The general system model and brief overview of MIMO clustered channel model is described in section 2. Spatial correlation coefficients of the CPA are described in section 3. Simulation results in clustered channel model are described in section 4. Finally conclusions are presented in section 5.

2. System Model

In this section, we describe the system model and present a brief overview of MIMO clustered channel model for indoor environments. We model the receive signal of a narrowband MIMO system, with Nt transmit antennas and Nr receive antennas is given by,

$$y = \sqrt{\frac{SNR}{N_t}} Hx + n \qquad \text{—(1)}$$

y = Received signal.

SNR= Signal to Noise Ratio.

Nt = Number of transmit antennas.

x = Transmit signal.

n = Zero Mean Additive Gaussian Noise.

H = MIMO channel matrix.

For spatially correlated MIMO channels, the matrix H is generated as [14]

$$H = \sqrt{\frac{K}{K+1}} H_{los} + \sqrt{\frac{1}{K+1}} H_{nlos} \qquad \text{—(2)}$$

K = Ricean K – Factor.

H_{los} = Line of sight component of H.

H_{nlos} = Non Line of sight component of H.

The LOS component of the channel is assumed to be rank one and from [15],[16] it is given by,

$$H_{los} = a(\Omega_{los,r}) \bullet a(\Omega_{los,t})^H \qquad \text{—(3)}$$

$a(\Omega)$ = Array response as a function of solid angle $\Omega = (\varphi, \theta)$.

$\Omega_{los,t}$ and $\Omega_{los,r}$ are the Angle of Departure (AoD) / Angle of Arrival (AoA) corresponding to the LOS component at the transmitter and receiver sides, respectively.

The NLOS channel matrix from [4],[17] is defined as ,

$$H_{nlos} = R_r^{1/2} H_w R_t^{1/2} \qquad \text{—(4)}$$

R_r = Transmit Spatial correlation matrix.

R_t = Receive Spatial correlation matrix.

H_w = Matrix of complex Gaussian fading coefficients.

N = Number of array elements.

This Geometry of the clustered channel model representing clusters and propagation paths is as shown in the fig.1.

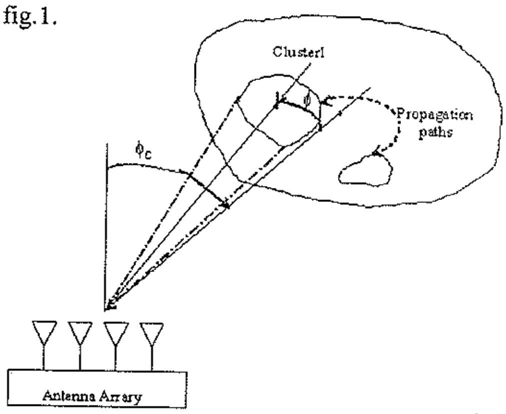

Figure 1 : Geometry Of The Clustered Channel Model Representing Clusters And Propagation Path

The angle φ_c is the mean AoA of the cluster, and φ is the AoA offset of the propagation path [9]. In clustered channel models, the scattering objects around the transmit / receive arrays are modeled as clusters. The entries of the spatial correlation matrix are a function of the transmit/ receive array and the spatial characteristics of the MIMO channel. Here it has considered only the azimuth directions.

3. Circular Patch Array and Uniform Linear Array

A. Circular Patch Array

The properties of circular microstrip antennas have been studied in [18]-[20]. In [18], it was shown that by exciting different modes of circular patch antennas, it is possible to obtain different radiation properties. In addition, by varying the size of the antennas as well as the feed location, different polarizations and radiation patterns can be generated in far-field. The orthogonality of the radiation patterns of circular patch antennas as a means to reduce correlation between the diversity branches of the MIMO array is used here.

The electric field of the n[th] mode excited inside the circular patch antenna as a function of its θ and φ far-field components from [9] are expressed as,

$$E_\theta^{(n)}(\phi,\theta) = e^{jn\pi/2}\frac{V_0^{(n)}}{2}k_0\rho(J_{n+1}+J_{n-1})\times\cos[n(\phi-\phi_0)]$$

$$E_\phi^{(n)}(\phi,\theta) = -e^{jn\pi/2}\frac{V_0^{(n)}}{2}k_0\rho(J_{n+1}+J_{n-1})\times\cos\theta\sin[n(\phi-\phi_0)] \quad \text{—(5)}$$

$V_0^{(n)}$ = Input Voltage.

k_0 = wave number.

$J_n = J_n(k_0\rho\sin\theta)$ = Bessel functions of the second kind.

n = order.

ρ = Radius of the microstrip antenna.

ϕ_0 =Reference angle corresponding to the feed point of the antenna.

To isolate the effect of pattern from space diversity, the patch antennas are assumed to be collocated and stacked on top of each other [19]. The same mode is excited for both elements of the MIMO array, and tunes the phase to produce orthogonal radiation patterns across the diversity branches. For the case of a two-element MIMO array, we feed one antenna with $\phi_0^{(1)} = 0$, and the other antenna with $\phi_0^{(2)} = \pi/(2n)$. As result of this feeding technique, we get orthogonal radiation patterns for any mode excited within the antennas. Mode 0 is discarded since it does not yield any pattern diversity, due to its isotropic radiation pattern over the azimuth directions.

The array response of the CPA from [4] is given by,

$$a_{cpa}(\phi) = \gamma(\rho,n)[\cos(n\phi),\sin(n\phi)]^T \quad \text{—(6)}$$

where,

$$\gamma(\rho,n) = e^{jn\pi/2}\frac{V_0^{(n)}}{2}k_0\rho[J_{n+1}(k_0\rho)+J_{n-1}(k_0\rho)]$$

ϕ = azimuth AoA / AoD.

The overall power radiated by the array is fixed to be a constant for any mode. Assume,

$$\|a_{cpa}(\phi)\|_2^2 = |\gamma(\rho,n)|^2 = N = 2 \quad \text{—(7)}$$

for any azimuth direction.

B. Uniform Linear Array

The performance of the CPA against a ULA is compared, and measured the gains achievable through a pattern over space diversity techniques. As for the CPA, it has been considered the case of a ULA with two elements, consisting of half-wavelength dipole antennas vertically polarized, with variable element spacing. It has been expressed the array response of this ULA as,

$$a_{ula}(\phi) = [1, e^{jk_0 d\sin\phi}]^T \quad \text{—(8)}$$

The power radiated by any array is a combination of the power radiated by each element, which depends on the input power through the reflection coefficients [21]. The conditions of constant "radiate" power is equivalent to constant "input" power between two arrays, as long as the reflection coefficients for the two arrays are the same.

C. Spatial Correlation Coefficients of the CPA

The spatial correlation coefficients of the CPA, assuming the MIMO clustered channel model is computed. The voltage received at the port of the l[th] patch from [22] is given by,

$$v_l = \int_{4\pi} e_l(\Omega) \bullet E_l(\Omega) d\Omega \qquad \text{—(9)}$$

The correlation coefficient across the l[th] and m[th] antennas of the MIMO array is given by,

$$r_{l,m} = \varepsilon\{v_l v_m^*\} = \int_{4\pi} S(\Omega) E_l(\Omega) E_m^*(\Omega) d\Omega \qquad \text{—(10)}$$

$S(\Omega) = \varepsilon\{e_l(\Omega) e_m^*(\Omega)\}$ is the power angular spectrum (PAS).

$$S(\Omega) = S_\phi(\phi) S_\theta(\theta)$$

$S_\phi(\phi) = P(\phi) * \delta(\phi - \phi_c)$ is the power azimuth spectrum.

$\delta(\phi)$ = Delta function. " * " deNotes the convolution.

$P(\phi)$ is generated according to the truncated laplacian distribution as defined in [15] ,

$$P(\phi) = \begin{cases} \dfrac{1}{\sqrt{2}\sigma_t (1 - e^{-\sqrt{2}\pi/\sigma_\phi})} \bullet e^{-|\sqrt{2}\phi/\sigma_\phi|}, if \phi \in [-\pi, \pi] \\ 0, otherwise \end{cases} \qquad \text{-(11)}$$

where σ_ϕ is the standard deviation of the power azimuth spectrum. The autocorrelation coefficient for the first and second antenna of the CPA is given by,

$$r_{11}(\phi_c, \sigma_\phi) = \frac{|\gamma(\rho,n)|^2}{(1 - e^{-\sqrt{2}\pi/\sigma_\phi})} \frac{(n\sigma_\phi)^2}{1 + 2(n\sigma_\phi)^2} \left[1 - e^{-\sqrt{2}\pi/\sigma_\phi} + \frac{\cos^2(n\phi_c)}{(n\sigma_\phi)^2} (1 - e^{-\sqrt{2}\pi/\sigma_\phi} \cos(n\pi)) \right]$$

$$r_{22}(\phi_c, \sigma_\phi) = \frac{|\gamma(\rho,n)|^2}{(1 - e^{-\sqrt{2}\pi/\sigma_\phi})} \frac{(n\sigma_\phi)^2}{1 + 2(n\sigma_\phi)^2} \left[1 - e^{-\sqrt{2}\pi/\sigma_\phi} + \frac{\sin^2(n\phi_c)}{(n\sigma_\phi)^2} (1 - e^{-\sqrt{2}\pi/\sigma_\phi} \cos(n\pi)) \right]$$

—(12)

This correlation coefficient is derived for the single-cluster channel, but its expression can be easily extended to multiple clusters by adding up the correlation coefficients due to each of the clusters, because of the independency of the clusters.

The cross correlation coefficients of the CPA is given by,

$$r_{12}(\phi_c, \sigma_\phi) = \frac{|\gamma(\rho,n)|^2}{2} \frac{\sin(2n\phi_c)}{1 + 2(n\sigma_\phi)^2}$$

D. Eigenvalues Of The Spatial Correlation Matrix

The eigenvalues of the correlation matrix for the CPA is given by,

$$\lambda_{12} = \frac{|\gamma(\rho,n)|^2}{2} \frac{1}{1 + 2(n\sigma_\phi)^2} \left\{ \left[2(n\sigma_\phi)^2 + \frac{1 - e^{-\sqrt{2}\pi/\sigma_\phi} \cos(n\pi)}{1 - e^{-\sqrt{2}\pi/\sigma_\phi}} \right] \pm \sqrt{\sin^2(2n\phi_c) + \left(\frac{1 - e^{-\sqrt{2}\pi/\sigma_\phi} \cos(n\pi)}{1 - e^{-\sqrt{2}\pi/\sigma_\phi}} \right)^2 \cos^2(2n\phi_c)} \right\} \qquad \text{—(13)}$$

As the mode number increases, the eigenvalues become closer to one, and the product $\lambda_1 \lambda_2$ is maximized. For high n, the radiation pattern of the circular patch antenna is characterized by a large number of lobes, which yields high pattern diversity. The approximate expression of the correlation coefficients is used for ULAs with a Laplacian distributed power azimuth spectrum and is given by,

$$\lambda_{12} = 1 \pm \frac{1}{1 + \frac{\sigma_\phi^2}{2} (k_0 d \cos\phi_c)^2} \qquad \text{—(14)}$$

d is the element spacing of the ULA. Increasing the element spacing produces high space diversity, which yields increased channel capacity and reduced error rate.

E. Channel Capacity

The tight upper bound to the ergodic capacity for spatial multiplexing (SM) systems (with equal power allocation across the transmit antennas) is considered. We assume zero mean single-sided (only at the transmitter) correlated MIMO channels. This upper bound is expressed as [9]

$$C \le \log_2\left[1 + 2SNR + \frac{SNR^2}{2}\lambda_1\lambda_2\right] \qquad (15)$$

λ_1 and λ_2 are the eigenvalues of the spatial correlation matrix R. The capacity increases as a function of the product of the eigenvalues (λ_1, λ_2).

4. Results and Discussion

Auto Correlation Coefficient for the first and second antenna of the CPA is shown in fig.2 and fig.3 respectively. Fig.4 shows the cross correlation Coefficient of the two antennas of the CPA (r12). If the mode number (n) increases, the frequency of the oscillations of the auto correlation and the cross correlation increases. This is due to the higher number of lobes in the radiation pattern for the higher order modes. The amplitude of the oscillations decreases for increasing mode number

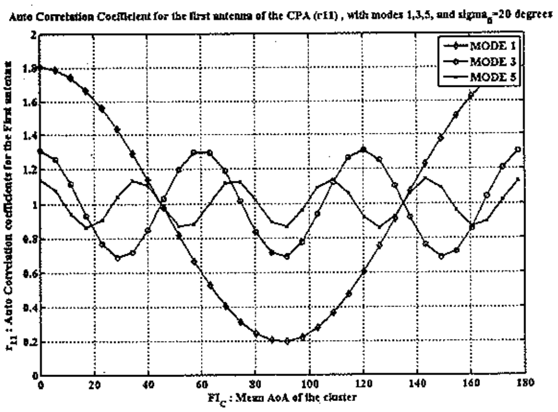

Figure 2 : Auto Correlation Coefficient For The First Antenna Of The CPA (R11)

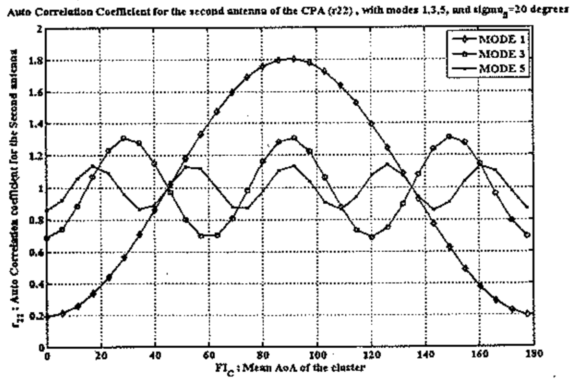

Figure 3: Auto Correlation Coefficient For The Second Antenna Of The CPA (R22)

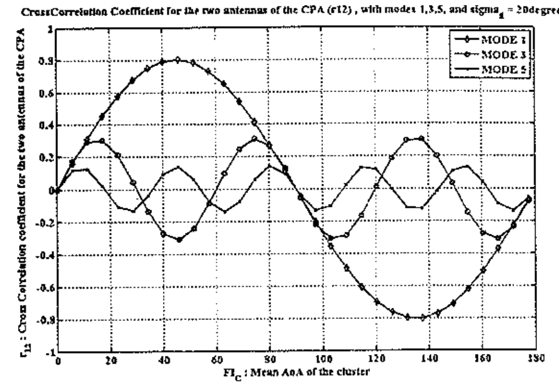

Figure 4 : Cross Correlation Coefficient Of The Two Antennas Of The CPA (R12)

Fig.5 shows Eigenvalues of the correlation matrix for CPA: mode=3.When the mode number increases, the eigen values become closer to one and the product of lamda1 and lamda2 is maximized. This is due to the higher decorrelation between the diversity branches of the CPA for higher order modes. This leads to the improved channel capacity and error rate performance.

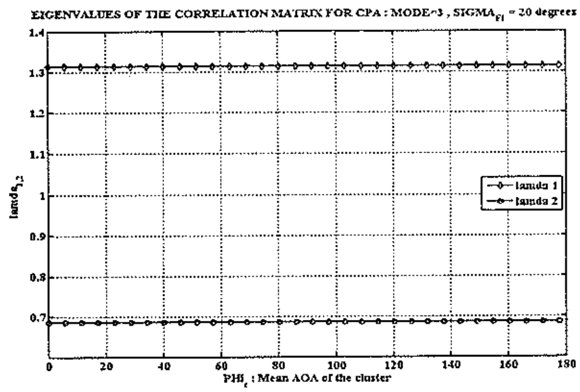

Figure 5: Shows Eigenvalues Of The Correlation Matrix For CPA: Mode

For high values of mode number, the radiation pattern of the CPA is characterized by a large number of lobes which yields high pattern diversity. Capacity increases as the function of the product of the eigen values (lamda1 lamda2). For mode 1, the CPA outperforms the ULA only for angles close to the end fire directions. For higher order modes, the CPA always provides better performance than the ULA. Fig.6 shows ergodic cpacity for the CPA and

ULA (d = 0.5 lamda). The maximum capacity of the CPA is close to its saturation point when mode 3 is employed. Higher the mode number, larger the size of the microstrip antenna for the fixed dielectric constant of the substrate and carrier frequency.

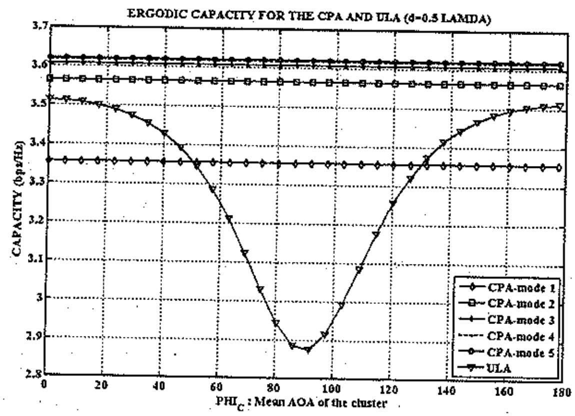

Figure 6 : Ergodic Capacity For The CPA And ULA (D = 0.5 Lamda)

5. Conclusion

In this paper we analyzed the performance of the MIMO system with the help of Circular Patch Array for different modes. The correlation is getting increased with lower order modes. Hence it is not suitable for higher capacity requirements. In the simulation results, the circular patch array with two elements is analyzed which exploits pattern diversity. The frequency of the oscillation for the correlations is also getting increased with increase in mode number. For reducing the correlation and in order to increase the capacity the higher order modes are suitable.

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