PERFORMANCE OF MULTIMODE ANTENNA ARRAYS IN DOUBLE DIRECTIONAL FINITE SCATTERING CHANNEL MODEL

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ABSTRACT

We have analysed the performance of multimode antennas arrays in double directional finite scatterers channel model with and without mutual coupling and compared the results with Omni directional antenna arrays. We have shown that multimode antennas are more suited as array elements as they perform better with regards to capacity and spatial correlation as a function of separation due to the more directional radiation patterns of transverse magnetic modes (TM).

1. INTRODUCTION

MIMO communication employs multiple antennas at the transmitter and receiver to increase system capacity and/or diversity. They are known to provide capacities many times that of the conventional Shannon limit and in principal can attain spectrum efficiencies in excess of tens of bits/sec/Hz. For an independent and identically distributed Rayleigh fading channel the rank of the channel matrix and likewise the capacity increases linearly with the increase in the number of antennas. But in general the MIMO channel environment is correlated due to limited scattering, and to electromagnetic phenomena such as mutual coupling. It has been known that although the mutual coupling may transform the individual radiation patterns of the antennas in an array possibly causing de-correlation of the signals received from varied directions in a Rayleigh fading environment [1], it also reduces the total power received on the channel with the effect that the overall capacity degrades especially for close spatial inter element separation [2]. In contrast the multimode antenna array exhibits very low mutual coupling. Therefore it is possible to have multiple communication sub channels within a confined space. The multimode antennas make use of multiple EM modes, with each having different radiation patterns [3]. These multiple EM modes provide the necessary de-correlation and hence exploit the scattering in a channel more effectively.

In this paper we have analysed the performance of multimode antenna arrays by extending the double directional finite scattering channel model [4] and designed a multimode antenna composed of stacked combination of short circuited ring patch antenna (SCRP) and circular patch antenna (CP) described in [3] which employs TM01 and TM11 mode respectively. This section also compares the spatial correlation as the function of spatial separation of antennas in an array for both the Omni and multimode antenna cases for a Laplacian power azimuth spectrum using the disk of scatterers model presented in [5].

2. FINITE SCATTERER CHANNEL MODEL FOR MULTIMODE ANTENNA

The finite scatterers channel model, models the channel by a set of discrete and finite multipath components. Fig.1 (a) illustrates this channel where the individual antenna elements at the receiver are replaced by multimode antennas or Omni directional antennas as the case may be. The channel is considered to be flat fading assuming that the delay spread is very small as compared to the symbol duration of the modulating signal. The signals applied at transmit and receive antenna elements can be represented by a length n_T and n_R column vector respectively. Each multipath component is assumed to have a distinct angle of departure (AoD) and a corresponding distinct angle of arrival (AoA). The path gain is represented by ξ_p and stands for the ratio of the electric/magnetic field component at receive and transmit end [4], where index p represents the index of the multipath component.

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(a) (b) (c)

Fig.1 (a) [8] Finite scatterers channel model. (b) Rx multimode antenna array showing inter element separation of 0.516 of a wavelength and ports. (c) Rx multimode antenna array showing separation of one wavelength.

Let the signal transmitted at an angle of $\phi_{T,p}$ be represented by $\psi^T{}_{T,p}(\phi_{T,p}).s$, where s is the data signal vector applied to the array. Then the signal received at the receive end (Rx) can be represented by $\psi_{R,p}(\phi_{R,p})\xi_p\psi^T{}_{T,p}(\phi_{T,p}).s$. Therefore the total received vector due to the contributions from all the paths can be given by

$$\mathbf{r} = \sum_{p=1}^{n_s} \boldsymbol{\psi}_{\mathbf{R,p}}(\boldsymbol{\varphi}_{\mathbf{R,p}})\boldsymbol{\xi}_{\mathbf{p}}\boldsymbol{\psi}^{\mathbf{T}}{}_{\mathbf{T,p}}(\boldsymbol{\varphi}_{\mathbf{T,p}}).\mathbf{s} \quad , \qquad \mathbf{r} = \boldsymbol{\Psi}_{\mathbf{R}}\, \boldsymbol{\Sigma}_{\mathbf{p}}\, \boldsymbol{\Psi}^{\mathbf{T}}{}_{\mathbf{T}}\, \mathbf{s} \tag{1}$$

where Ψ_R, Ψ_T are matrices whose columns are receive and transmit steering vectors respectively and Σ_p is the diagonal matrix composed of path gains. p stands for the path number and varies from $p=1,....,n_s$,where n_s is the total number of scatterers. At transmit end the antenna are Omni-directional antennas therefore their gains are assumed to be uniform for the whole azimuth while the steering vectors within the Ψ_R incorporate the directional multimode antenna gain and phase as a function of angle of arrival. For a linear array, in general the elements of the steering vector, as a function of angle of arrival or departure can be given as

$$\psi_{(\phi)} = \exp(-j\frac{2\pi}{\lambda}nl\cos(90-\phi)) \qquad n = 0,....,n_{T,R}-1 \text{, where } \lambda \text{ is the wavelength} \tag{2}$$

The shape of the complete channel matrix from (1) and (2) for our case can be represented as

$$\mathbf{H} = \begin{bmatrix} G_1(\phi_1)\cdot\psi_{R1}(\phi_1) & G_1(\phi_2)\cdot\psi_{R1}(\phi_2) & \cdots & G_1(\phi_{n_s})\cdot\psi_{R1}(\phi_{n_s}) \\ G_2(\phi_1)\cdot\psi_{R2}(\phi_1) & G_2(\phi_2)\cdot\psi_{R2}(\phi_2) & \cdots & G_2(\phi_{n_s})\cdot\psi_{R2}(\phi_{n_s}) \\ \vdots & \vdots & \cdots & \vdots \\ G_D(\phi_1)\cdot\psi_{n_R}(\phi_1) & G_D(\phi_2)\cdot\psi_{n_R}(\phi_2) & \cdots & G_D(\phi_{n_s})\cdot\psi_{n_R}(\phi_{n_s}) \end{bmatrix} \begin{bmatrix} \xi_1 & 0 & \cdots & 0 \\ 0 & \xi_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & 0 \\ 0 & 0 & 0 & \xi_{n_s} \end{bmatrix} \begin{bmatrix} \psi_{T1}(\phi_1) & \cdots & \cdots & \psi_{n_T}(\phi_1) \\ \psi_{T1}(\phi_2) & \ddots & \cdots & \psi_{n_T}\phi_2) \\ \vdots & \cdots & \ddots & \vdots \\ \psi_{T1}(\phi_{n_s}) & \cdots & \cdots & \psi_{n_T}\phi_{n_s}) \end{bmatrix} \tag{3}$$

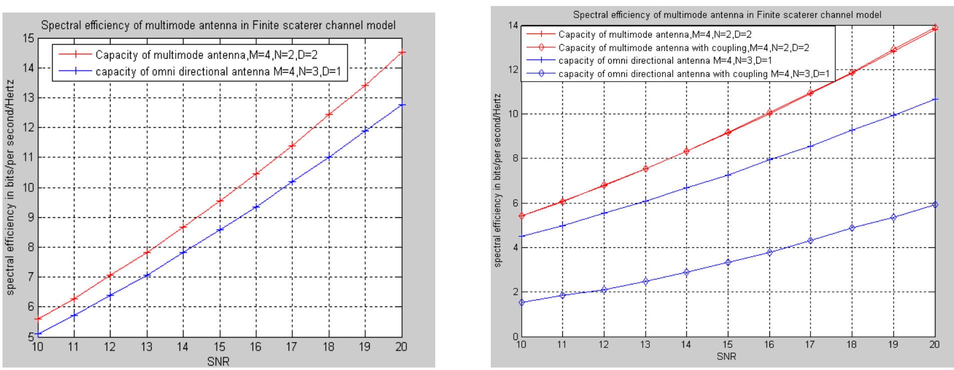
where G_j represent the complex gains as a function of direction and $j=1,..,D$ represent the mode number. Noise at the individual elements is considered to be circularly symmetric zero mean Gaussian random variables with a power given by $n^H n = N$. The capacity of the multimode antennas is given by

$$C = B\sum_{i=1}^{k}\log_2(1+\frac{\lambda_i S}{n_T N}) \tag{4}$$

Here S is the total signal power transmitted and λ_i stands for the eigenvalues of the channel autocorrelation matrix.

2.1 Simulation of Multimode Antennas in a finite Scatterer Channel model

We have simulated a scenario where four Omni-directional antennas are widely separated at the base station such that the mutual coupling between the elements at the transmit end can be ignored and two multimode antennas are located at the receive end. This (4×2) MIMO communication system is compared with (4×3) MIMO communication comprised only of Omni directional antennas. Scatterers are assumed to be distributed uniformly within an area by assuming uniform distribution of AoA and AoD. Steering vectors can be obtained by (2).The path gains are taken to be complex Gaussian random variables that are independently fading and hence uncorrelated. The relative mean power of all the paths has been assumed to be equal. We have averaged the channel autocorrelation matrix over 5000 random channel realisations. Fig. 2 show the results which clearly shows that the multimode antenna array performs better in the finite scatterers channel model with Omni directional scattering than that of Omni directional antennas. This is due to directional radiation patterns of the TM01 and TM11 modes, which are Omni- directional in azimuth and directional to broadside respectively. Further the two modes are also orthogonal in the azimuth as shown in Fig.3. Signal to noise ratio (SNR) is taken in dB. It is observed that even when the inter element spacing was reduced and mutual coupling is included, the radiation pattern do not lose the basic orthogonal structure though the directivity is a little compromised. Also at the intuitive level the coupled patterns imply that the input impedance of individual port has not varied much and is still matched to the 50 ohm waveguide port used in the CST microwave simulation.



(a) (b)

Fig.2 MIMO system capacity for Rx multimode antenna array (a) For inter element separation as shown in fig.1c (b) For inter element separation as shown in fig.1b. 'D', 'M', 'N' stand for number of modes, transmit and receive antennas respectively.

This allows us to extract maximum power unlike the Omni directional antennas where the real component of the input impedance approaches zero in the limit as a function of inter element spacing [1].This is evident through the scattering parameters in Fig.3. Fig.3 also shows the coupled patterns of the individual array elements which in case of the multimode antenna array are respective ports. At small inter element spacing the radiation pattern in case of Omni directional antennas is symmetrically opposite and therefore reduces the Frobenius norm of the channel [2]. However the effective angular spread of the MIMO array is also reduced while the coupled patterns of the multimode antennas contribute more towards de-correlating the received signals from different directions.

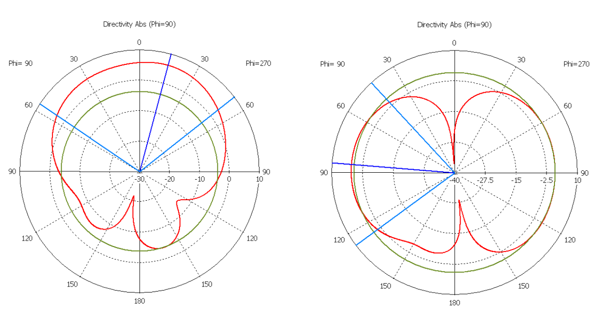


Fig.3 (a) Coupled radiation patterns of port1&port 2, which are TM11&TM01 modes respectively for the case shown in fig.1b

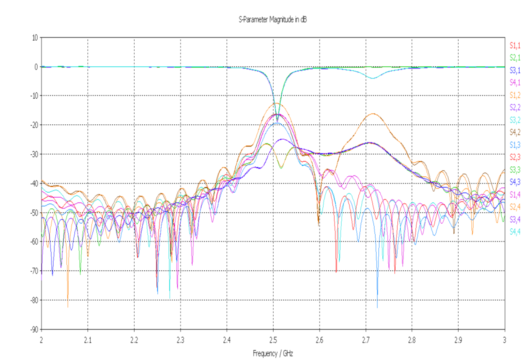
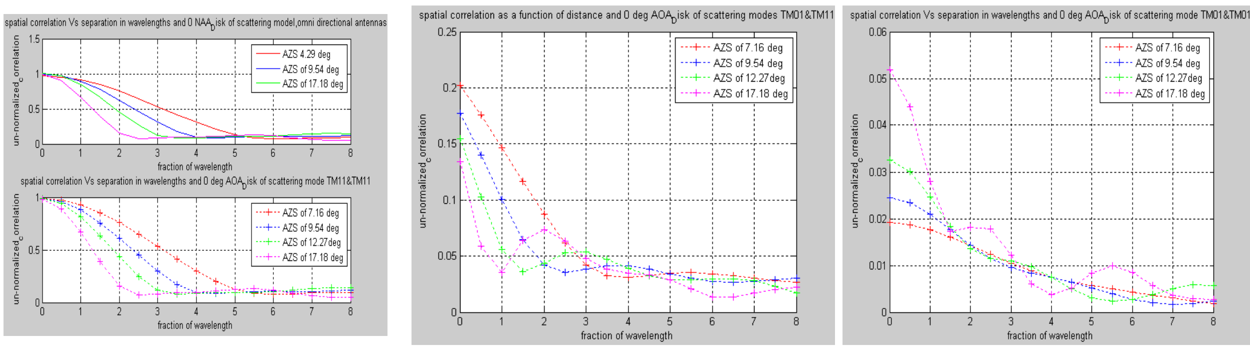


Fig.3 (b) Scattering parameter of Rx multimode for the case shown in fig.1b

Spatial correlation of multimode antennas was estimated through Monte Carlo simulation by incorporating the directional complex radiation pattern gains of the respective TM modes within the steering vectors as shown by equation (3) and using the disk of scatterers model [5] simulating a Laplacian distribution of power azimuth spread as seen at the receiver array. Fig.4 demonstrates the extent to which multimode antennas can effectively exploit the scattering in the channel due to differing and more directive radiation patterns, and hence provide improved decorrelation.



(a) (b) (c)

Fig.4 Spatial Correlation of multimode antennas as a function of wavelength excluding mutual coupling. (a) Spatial Correlation between TM11 mode (b) Spatial Correlation between TM01&TM11 modes. (c) Spatial Correlation between TM01 modes

Correlation between orthogonal modes is very low compared to that between the same modes for small separation. This is because for the same modes, correlation is essentially the power received through a small azimuth spread angle, 17.18 degrees at maximum. In the case of TM01 this spread is centred around the null of the antenna pattern: hence the total received power is low. Note that the un-normalised correlation at zero separation corresponds to the received power: for TM01 this is low. This may result in power imbalances which may affect the diversity of the system especially for the case of restricted power azimuth spread. The solid lines and dotted lines represent the spatial correlation of Omni-directional antennas and relevant TM modes of multi mode antennas respectively. The multimode antennas manifest similar or better decorrelation performance as compared to Omni-directional antennas.

4. CONCLUSION

It has been shown that multimode antennas are ideally suited as array elements due to their directional TM modes and low correlation aspects with or without mutual coupling as compared to Omni directional antennas whose capacity degrades for close inter element separation with mutual coupling.

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