MIMO Channel Modeling Using the Multiple Point Scatterers

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Abstract – Any Channel model describes the propagation characteristics of signals in mobile communication environments and is very critical for the performance evaluation of wireless communication systems. A simple stochastic MIMO model channel using multiple point scatterers at Mobile station (MS) has been presented in this paper. This model uses the correlation matrices at the mobile station (MS) with circle of scatterers and base station (BS) located slightly away from it. The mat lab simulation results with individual three modes along with their singular values are obtained by the diagonalization process show their Cumulative distribution functions (CDF), time-varying capacities and the SIMO and the MIMO capacities.

Keywords— MS, BS, SIMO, MIMO,SCM, CDF

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I. INTRODUCTION

Advancement in wireless technologies and antenna array configurations has increased in the volume of ongoing researches in wireless channel modeling. The communication channel represents a major component that determines system performance. Modeling of channels is essential for the design of wireless systems. The performance of a new technology known as MIMO (Multiple Input Multiple Output),which involves a state-of-the-art combination of MEAs (Multi Element Array) and digital signal processing, is introduced to achieve higher spectral efficiency compared to the conventional SISO (Single Input Single Output) technology currently deployed in wireless communication systems. The MIMO concept is defined as a radio link with M elements at one end and N elements at the other end. The main benefits of using the MIMO technology lie in the creation of min(M,N) orthogonal information sub channels, the combination of Transmitter and Receiver diversity, and the increased antenna gain. The performance of the MIMO technology is directly dependent on the correlation properties of the MIMO radio propagation channel. The MIMO system operates at a level of complexity that exploits channel space-time resources required to access the potential performance of practical multi-antenna links [1]. In a MIMO wireless system, the transmitted signal interacts with the environment in a very complex way. This is as a result of reflections, diffractions and signal scattering resulting from objects/scatterers in the signal path and electromagnetic waves around objects. A continuous succession of paths is produced by each scatterer joining the transmitter and the receiver. Thus, a channel model for non-line of sight (NLOS) propagation must involve details about the multipath environment. In a multipath environment, the communication link can be described by properties such as amplitude fade variations, carrier phase; time delay spread information, power delay profile, angle of arrival and departure, Doppler shift and the number of multipath components [2]. Consequently, realistic assumptions could be made so that postulated channel models could facilitate performance assessment of potential space-time coding approaches for practical propagation scenarios.

This paper provides MIMO channel modeling using the multiple point scatterers in Correlated scenario. In a situation with Line-of-Sight (LOS) at MS or BS of the radio link, the elements of H exhibit a certain correlation which results in a low rank scenario hence providing a lower number of Eigen values. A quantitative description of the MIMO gain performance is the temporal representation of the Eigen values. Another method to present the Eigen values is by using their CDF.

II. MIMO CHANNEL MODEL

MIMO establishes a radio link with M antennas at the BS and N antennas at the MS as pictured in Figure 1. For uplink the Transmitter is at the MS and the Receiver at the BS while for downlink, the roles are reversed.

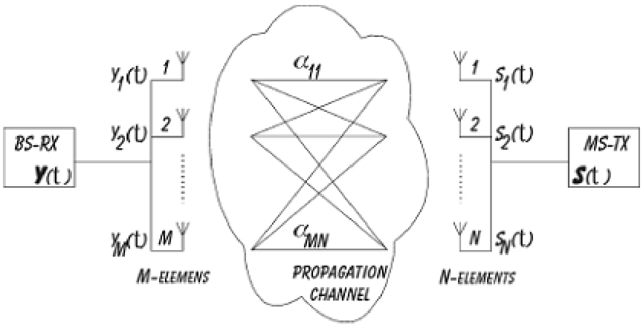

Fig.1. Two antenna arrays in a scattering environment. (Uplink situation)

The received signal vector $y(t)$ at the BS antenna array is denoted by

$$y(t) = [\, y_1(t), y_2(t), \dots \dots \dots \dots .\, y_M(t)]^T \qquad (1)$$

Where $yM(t)$ is the signal at the mth antenna element and [.]T denotes the transpose operation. Similarly, the transmitted signals at the MS, $sN(t)$, define the vector $s(t)$

$$s(t) = [\, s_1(t), s_2(t), \dots \dots \dots \dots .\, s_N(t)]^T \qquad (2)$$

The vectors $y(t)$ and $s(t)$ are related by the following expression

$$Y(t) = H(t)s(t) + n(t) \qquad (3)$$

Where $n(t)$ is additive white Gaussian noise and $H(t)\in \mathbb{C}M\times N$ is the instantaneous narrowband (NB) MIMO radio channel matrix and $\mathbb{C}$ represents Complex domain. $H(t)$ describes the connections between the MS and the BS and can be expressed as

$$H(t) = \begin{bmatrix} \alpha_{11}(t) & \alpha_{12}(t) & \cdots & \alpha_{1N}(t) \\ \vdots & & \ddots & \vdots \\ \alpha_{M1}(t) & \alpha_{M2}(t) & \cdots & \alpha_{MN}(t) \end{bmatrix} \qquad (4)$$

Where $\alpha MN(t)$ is the complex NB transmission coefficient from element n at the MS to element m at the BS. Due to insufficient spacing between antenna elements and limited scattering in the environment, the elements of the channel matrix are not always independent. Scatterers Models usually involving distributed. Scatterers are there to capture the channel characteristics. As long as the constructed scattering environment is reasonable, such a model can often capture the essential characteristics of the MIMO channel.

III. THE EIGENANALYSIS METHOD AND INTERPRETATION

Mathematically, the number of independent sub channels between two antennas can be estimated by using the singular value decomposition (SVD) of the matrix H or the Eigen value decomposition (EVD) [3] of the instantaneous correlation matrix R defined as

$$R = HH^H \quad \text{or} \quad R = H^H\mathrm{H}$$

Where [.]H represents Hermitian transposition, i.e. the transpose conjugate.

The derivation of the parallel independent channels is summarized below where U and V are unitary matrices, Σ and Γ are diagonal matrices and u and v are the left and right singular vectors, respectively. There is an important relationship between the SVD of H and the EVD of R such that $\sigma k2 = \gamma k$where σk is the kth singular value and γk is the kth Eigen value and where K is the maximum number of Eigen value. Γij denotes the elements (Scatterers' reflection coefficient) of the matrix Γ.

SVD method is represented as

$$H = U\,\Sigma\, V^H$$

Where Σ=$diag$ (σ1,……σK) , σ1≥σ2….≥σK≥0

and

$$U = [u_1, \dots \dots ..\, u_M] \in \; C^{M\times M}$$

$$V = [v_1, \dots \dots ..\, v_N] \in \; C^{N\times N}$$

Where C is the capacity normalized to the system bandwidth.

EVD method is represented as

$$HH^H = U\Gamma U^H \text{ or } H^H H = V\Gamma V^H \;;\;\; \Gamma_{ij} = \Sigma_{ij}^2$$

$$\text{Where } \Sigma = diag\,(\gamma_1, \dots \dots \gamma_K) \;\; ; \gamma_1 \geq \gamma_2 \dots . \geq \gamma_K \geq 0$$

Unless otherwise mentioned, the normalization is made with respect to the mean power $|\alpha mn|2$ between all the single MS and the single BS element so that λk is defined as

$$\lambda_k = \frac{\gamma_k}{E\left[\frac{1}{MN}\;\sum_{m=1}^{M}\sum_{n=1}^{N}|\alpha_{mn}|^2\right]} \qquad (5)$$

Where E [.] is the expectation over time (or distance). In order to keep the reading simple, the explicit term normalized is dropped. Irrespective of the numerical method used to perform the analysis, a channel matrix H may offer K parallel sub channels with different power gains, λk, where

$$K = Rank\;(R) \;\leq \min(\,M, N),$$

and the functions Rank (·) and min (·) return the rank of a matrix and the minimum value of the arguments, respectively.

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In engineering terms, u and v are also referred to as the weight vectors while the kth Eigen value can be interpreted as the power gain of the kth orthogonal sub channel. Correlated scenario. In a situation with Line-of-Sight (LOS) or low AS at one or both ends of the radio link, the elements of H exhibit a certain correlation which results in a low rank scenario hence providing a lower number of Eigen values.

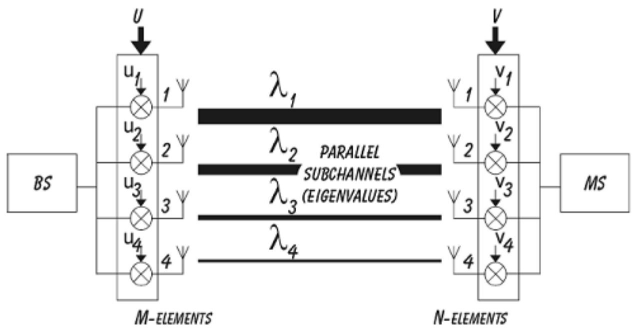


Fig.2: Illustration of parallel sub channels for a 4 × 4 MIMO MEA topology.

Figure.2 shows 4×4 MIMO MEA topology. In such a configuration, MN = 16 radio links, αMN, are created, but only 4 orthogonal sub channels with power gain $\lambda 1$ to $\lambda 4$ are available. The difference in the thickness of the lines emphasizes the difference in gain of the parallel sub channels so that

$$\lambda_1 \geq \lambda_2 \geq \ldots \geq \lambda_K \geq 0$$

To get the weight vectors, it is numerically more convenient to use the SVD of H while to obtain the Eigen value it is easier to use the EVD. The EVD technique is the optimal way to extract the power gain of the MIMO sub channels. However, if this technique is to be optimal in a practical system implementation, the proper unitary matrix U and V must be applied at the respective ends of the link. Consequently, the EVD method is only useful when the channel is known, i.e., when the information of the radio channel is available at both the transmitter and the receiver.

IV. THE CORRELATED MIMO SCENARIO

This section presents the different MIMO propagation scenario. The BS is elevated free of local scatterers and MS is at ground level is considered. The scatterers are uniformly distributed on a ring around the MS with a given radius as shown in Fig.2. Each of the scatterers on the ring is referred to as effective scatterers, and model the effect of several scatterers within a small area.

The Azimuth Spread (AS) is defined as the root second central moment of the Power Azimuth Spectrum (PAS). The PAS is closely related to the spatial correlation at the Multi Element Array (MEA), i.e., depending on the spatial separation between the elements of the MEA, a low AS is equivalent to a high spatial correlation coefficient and vice versa.

The enhancement in the radio link from the MIMO technology can be expressed in terms of antenna gain, diversity order and throughput performance. As already presented in [6], the antenna gain and the diversity order obtained from a MIMO system depend on the scattering environment and especially on the AS at each end of the MIMO radio link. These findings are summarized in Table I, since they outline MIMO performance very well for different scenarios. In Table 1, the antenna radiation pattern of each element of the MEA is assumed isotropic and the strongest Eigen value $\lambda 1$.

TABLE. 1. ANTENNA GAIN AND DIVERSITY ORDER IN A MIMO TECHNOLOGY.

AS at MS	AS at BS	Scenario	Mean gain	Diversity order
Low	Low	Correlated	MN	1
Low	High	Correlated	MN	M
High	Low	Correlated	MN	M
High	High	Decorrelated	$\sim(\sqrt{M}+\sqrt{N})^2$	MN

V. THE MIMO CHANNEL CAPACITY

MIMO systems can offer more information capacity compared to a conventional SISO system. The Shannon's formula for a SISO radio channel is expressed as:

$$C = \log_2(1 + \varsigma)$$

Where ς (sigma variant) is the SNR.

For the MIMO technology, Telatar [7] presented the total Shannon's capacity, for uniform power allocation strategy, as

$$C = \log_2(\det(I + Q\, H^H\, H)) \quad (6)$$

Where I is the identity matrix, Q is the signal covariance matrix, det (.) is the determinant and log2 is the logarithm base 2. This formulation is often used by the MIMO community.

Equation (6) can be rewritten so as to emphasize the influence of the K parallel sub channels and the total Shannon's capacity is defined as

$$C = \sum_{k=1}^{K} \log_2 \left(1 + \lambda_k \frac{P_k}{\sigma_n^2} \right) \quad (7)$$

Where ςk is the SNR for the kth subchannel and is defined as

$$\varsigma_k = \lambda_k \frac{P_k}{\sigma_n^2}$$

Where Pk is the power assigned to the kth sub channel and $\sigma n2$ is the noise power.

Hence, (7) can be rewritten as

$$C = \sum_{k=1}^{K} \log_2 \left(1 + \lambda_k \frac{P_k}{\sigma_n^2} \right) \quad (8)$$

Depending on the power allocation scheme (Either water filling theorem or Uniform power allocation scheme) employed, the total transmitted power is distributed in a different manner between sub channels. When considering the total capacity offered by the MIMO set-up, the total mean SNR per Receiver antenna is defined as

$$SNR = \frac{E\,[\,P_{Receiver}\,]}{\sigma_n^2} = \frac{E\,[\,P_{Transmitter}\,]}{\sigma_n^2}$$

When the channel is known, i.e., when the information of the radio channel is available at the Transmitter, it is possible to apply the EVD and the kth Eigen value can be extracted.

VI. RESULT ANALYSIS AND DISCUSSIONS

Main characteristics of wireless channels are channel strength varies with time, frequency and space relative speed between transmitter and the receiver plots the actual multiple point-scatterers scenario is simulated according to Figure.3. Here a circle of scatterers was assumed about MS. For convenience, a circle-of-scatterers scenario is assumed. This scenario is used for assessing diversity gains at the BS and MS sides.

Figure.4 illustrates the nine time series corresponding to all possible antenna pairs. A quantitative description of the MIMO gain performance is the temporal representation of the Eigen values. Here where the AS is high at both the BS and MS, whereas Figure 5 presents a situation where the AS is low at the BS and high at the MS. Figure.5 also illustrates the time series of the three singular values obtained in the diagonalization process The behavior of the Eigen values can be summarized in two items: they fluctuate with time and the strength of each λk strongly varies depending on the propagation scenario, i.e., correlated or uncorrelated.

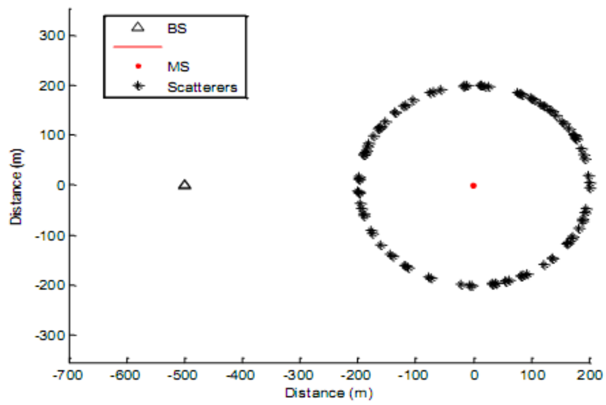


Fig.3. Simulated scenario

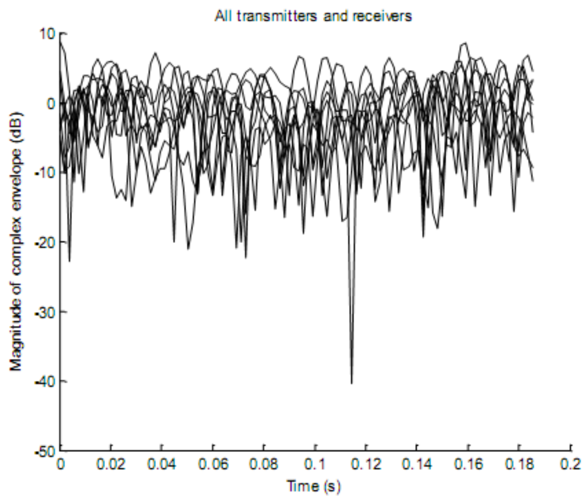
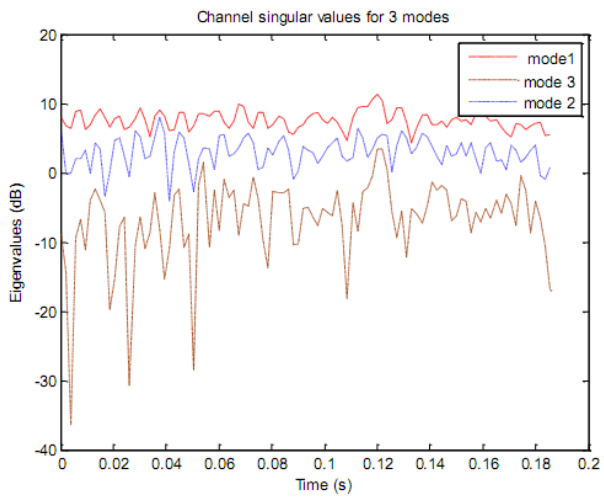


Fig.4. Time series for all Tx–Rx antenna pairs (De correlated scenario)



Fig,5. Variation of the Eigen values over time

Another method to present the Eigen values is by using their cumulative distribution function (CDF). The CDF representation is also very useful when interpreting the diversity performance in a MIMO system. The steepness of the slope of the CDF reflects the diversity order. The steeper the slope, the less amplitude of the fluctuation in the signal, i.e., the fades due to the multipath are less deep, and therefore a higher degree of diversity is obtained as shown in Figure .6. The slope is an indication of the amplitude of the Eigen value fluctuations. Figure.6 also presents the empirical CDF of the normalized Eigen values compared to a Rayleigh SISO channel. The graphs should read as follows. At the 10-1 level a power gain of 19 dB is achieved using MIMO (mode-3) compared to a SISO (mode-2) set-up. The 10-2 CDF level is often used is a typical measure for system-level performance.

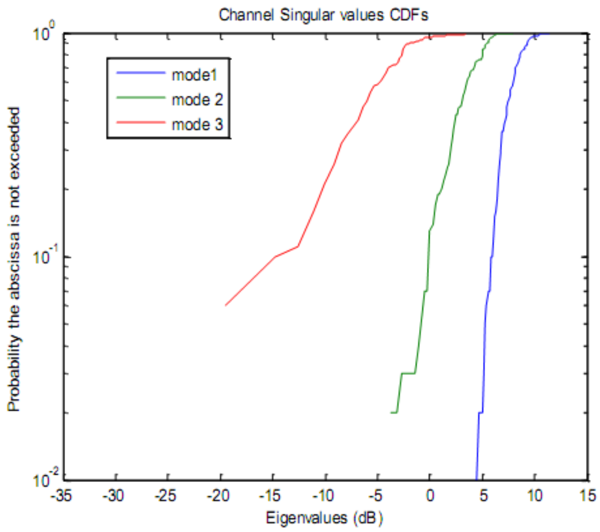


Fig.6. Channel singular value time series.

Fig.7 shows the time-varying capacities of the individual MIMO modes, the SIMO and the MIMO capacities. Figure 8. shows the SIMO and MIMO capacity CDFs. It can clearly be observed how MIMO brings about a drastic increase in capacity.

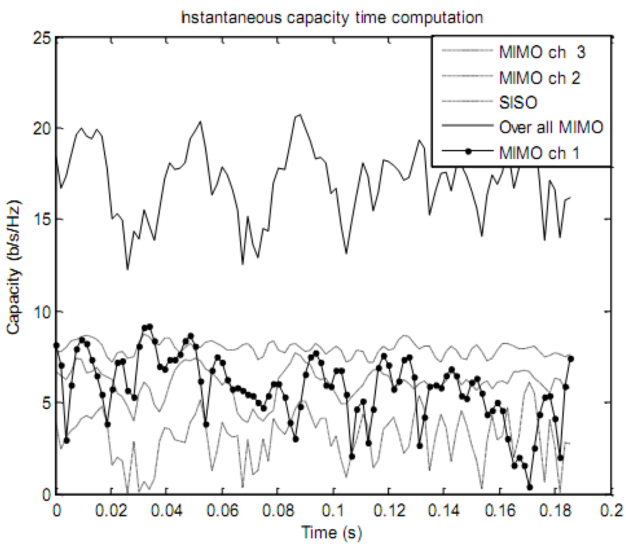


Fig.7. Instantaneous capacity time series for SISO, individual MIMO modes and overall MIMO cases.

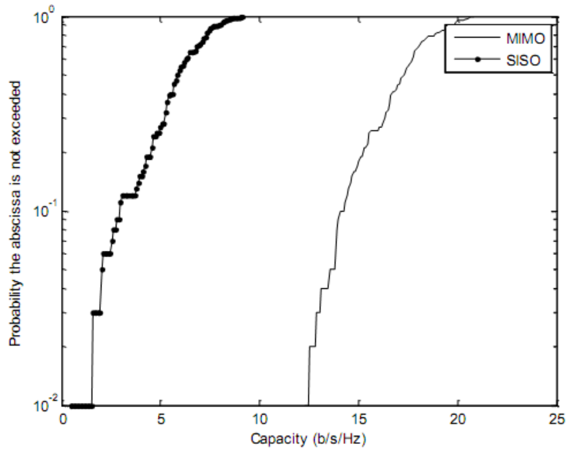


Fig.8. Capacity CDFs for SISO and MIMO cases

VII. SUMMARY AND CONCLUSION

This paper presents a generic model of MIMO wireless channel. Most important propagation mechanisms of a established physical model, taking into account the scattering near BS and MS has been the main feature of this proposed work. The simulation of the MIMO channel using the multiple point scatterers approach surrounding MS has been done. The MIMO channel capacity (probability) has been increased substantially. However, this proposed work has shown preliminary results that indicate the differences between the MIMO and SISO in terms of The CDF representation which is also very useful to represent diversity performance in a MIMO system.

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