International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-8 Issue-2S, December 2018

# Performance Analysis of Massive MIMO system for 2D/3D channel Models in 4G/5G Networks

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***Abstract---** Channel capacity, data rate and spectral efficiency are the most important demanding factors in wireless communications. Massive MIMO (Multiple Input Multiple Output) can improve these factors in the next generation 5G wireless communication networks. In massive MIMO, terminals are equipped with array of antennas for the same time frequency slot to assist multiple users with fast data rates and reliable performance. The performance of massive MIMO system with mutual coupling for realistic channel models is analyzed using Monte-Carlo simulations for different antenna configuration. The Geometry Based Stochastic Models (GBSMs) and Correlation Based Stochastic Models (CBSMs) and are used for the theoretical and realistic channel model analysis. In this paper, channel capacity is analyzed for the different antenna configurations in considering with CBSM and GBSM channel models. It is inferred that the 2D array configurations performed well as compared to 1D antenna array. This is possibly due to very low mutual coupling of 2D array configurations.*

***Keywords-**Massive MIMO; CBSM model, GBSM model, channel capacity, mutual coupling*

## I. INTRODUCTION

In MIMO wireless system, more than one antenna elements are at the transmitting and receiving end. The antennas transmit the information over the channel in a same band of frequency. So, the signals are distributed in different path in the channel. Moreover, due to multiple signal transmissions, the system experiences a spatial form of signal dependent interference referred as co-antenna interference. The challenge for the receiver is to mitigate the co-antenna interference problem and make the receiver to provide a spectacular increase in spectral efficiency [1].

If multiple antennas are used at both transmitting and receiving end, then the channel capacity increases with number of antennas in linear fashion [2]. High transmitted data rate may be attained by transmitting different data information on each antenna in a high scattering environment. Quality of service is improved through space diversity by transmitting same signal over multiple antennas [3]. So the MIMO system increases the channel capacity and quality of the service.

To increase the benefits of the MIMO, huge number of antenna elements are used. In Massive MIMO, hundreds of antennas are used at the transmitting and receiving end, which improves the spectrum efficiency, data rate and reduce the radiated power of the 4G/5G networks [3, 4]. These antennas are arranged in different array configurations to increase the system capacity. The most commonly used array configurations are linear, rectangular, spherical and cylindrical antenna arrays. Linear array is a one dimensional antenna array whereas rectangular, spherical and cylindrical are 2D antenna arrays which are more generally used in practical systems.

The system capacity is directly related to the NT transmit and NR receive antenna elements. The channel properties and antenna configurations play a major role in analyzing the channel capacity. The array configurations decide the mutual coupling and correlation matrix, furthering the capacity of massive MIMO system. The most commonly used channel models in massive MIMO systems are correlation-based stochastic and geometry-based stochastic models.

Section II discusses the channel models used in 4G/5G networks. Section III reviews MIMO channel capacity, Section IV discusses the results.

## II. CHANNEL MODEL

In massive MIMO system, stochastic correlation and geometry based channel models are commonly used to analyze the performances of the wireless systems [3]. The CBSMs channel model is used for theoretical analysis whereas GBSMs are the realistic channel models. The Rayleigh, correlation and mutual coupling channel models are the CBSM models and 2D and 3D channel models are the GBSM models.

### *A. Correlation-based stochastic models (CBSMs)*

A.1 IID Rayleigh Fading Channel Model

The IID Rayleigh fading channel is the most common theoretical channel model. It has Independent Identically Distributed (IID) zero mean, unit variance and complex values.

$$h_{ij}=N\left(0,1/\sqrt{2}\right)+jN\left(0,1/\sqrt{2}\right) \quad (1)$$

**Manuscript published on 30 December 2018.**
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where $h_{ij}$ represents the complex gains between the $j^{th}$ transmit and $i^{th}$ receive antennas. The channel H of a MIMO system with transmit and receive antennas is defined by the matrix $N_R \times N_T$ and it is written as [5]

$$H=\begin{bmatrix} h_{1,1} & \cdots & h_{1,n_T} \\ .. & .. & .. \\ h_{n_R,1} & \cdots & h_{n_R,n_T} \end{bmatrix} \quad (2)$$

In a high scattering regions, the gains are usually independent identically distributed Gaussian random variables and there is no spatial correlation and mutual coupling effects.

A.2 Spatial Correlation Model

In a multi-element antenna system, spatial correlation is a used to find the relation between two antenna signals. It depends on array geometry, spacing and the energy distribution. Mathematically, the spatial correlation coefficient between two antennas is expressed as,

$$\rho=\frac{\int_{\theta_0-\Delta_\theta}^{\theta_0+\Delta_\theta} E_1(\theta)E_2^*(\theta)p(\theta)\sin\theta d\theta}{\sqrt{P_1P_2}} \quad (3)$$

For two-dimensional Power Azimuth Spectrum (PAS), the spatial correlation coefficient is given as

$$\rho=\frac{\int_{\varphi_0-\Delta_\varphi}^{\varphi_0+\Delta_\varphi}\int_{\theta_0-\Delta_\theta}^{\theta_0+\Delta_\theta} E_1(\theta,\varphi)E_2^*(\theta,\varphi)p(\theta,\varphi)\sin\theta d\theta d\varphi}{\sqrt{P_1P_2}} \quad (4)$$

Where P1 and P2 are the mean received powers of antenna 1 and 2 respectively.

MIMO correlated channel model is [6],

$$H=\left[R_{rx}\right]^{1/2} H_{IID}\left(\left[R_{tx}\right]^{1/2}\right)^T \quad (5)$$

$R_{tx}$ and $R_{rx}$ are the correlations of the antennas. The channel matrix given as

$$R=\begin{bmatrix} 1 & \rho_{1,2} & \rho_{1,3} \\ \rho_{2,1} & 1 & \rho_{2,3} \\ \rho_{3,1} & \rho_{3,2} & 1 \end{bmatrix} \quad (6)$$

where $\rho_{i,j}$ is the transmit antenna correlation values. The complex correlation coefficients are calculated based on the power azimuth spectrum, the mean AOD of the transmit antennas and the mean AOA of the receive antennas. The correlation with the effect of mutual impedance at transmitter and receiver are given by

$$R_{tx}=C_{tx}r_{tx}C_{tx}^H$$
$$R_{rx}=C_{rx}r_{rx}C_{rx}^H \quad (7)$$

where $C_{tx}$ and $C_{rx}$ are the mutual coupling matrices for the transmit and receive antennas and $r_{tx}$ and $r_{rx}$ are the correlation matrices of transmit and receive antennas. Figure 1 shows the spatial correlation of array with coupling, thus indicating that the spatial correlation between the antennas is reduced with mutual coupling.

The practical MIMO implementation is affected by spatial correlation and mutual coupling. When many antennas are placed in both the transmitter and the receiver, capacity reduces due to the increase in correlating effect between the antennas. When the antenna elements are placed together, mutual coupling comes into picture, which decreases the correlation which in turn increases the capacity.

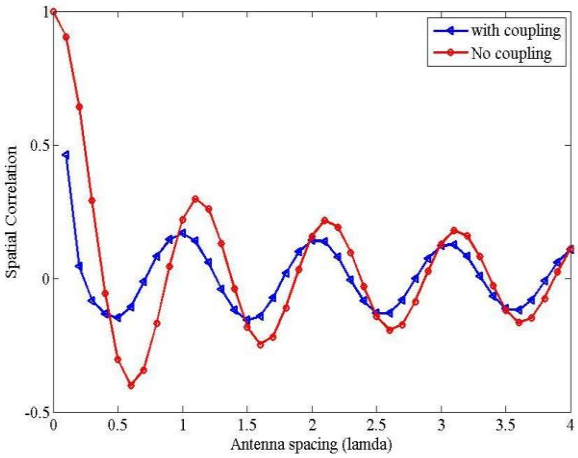


**Figure 1 Spatial correlation of the array antenna in terms of antenna spacing**

*B. Geometry -based stochastic models (GBSMs)*

WINNER II and 3GPP are the most commonly used 3D channel models. The 3GPP model is a system level for simulating fading environments which includes urban macro, micro cells, suburban macro and rural macro-cells [6]. The 'N' number of clusters with scatterers is present in the fading environment. Resolvable path represents clusters and each cluster has M unresolvable sub paths. Shadow fading, angular and delay spreads, powers, delays and directions are derived from the second moments and tabulated distribution functions [7, 8]. The channel element is given as

$$h_{u,s,n}(t)=\sqrt{\frac{P_n}{M}}\sum_{m=1}^{M}\exp[j(kd_s\sin(\theta_{n,m,AOD})+\varphi_{n,m})]$$
$$\times\exp[jkd_u\sin(\theta_{n,m,AOA})]\times\exp[jk\|v\|\cos(\theta_{n,m,AOA}-\theta_v)t] \quad (8)$$

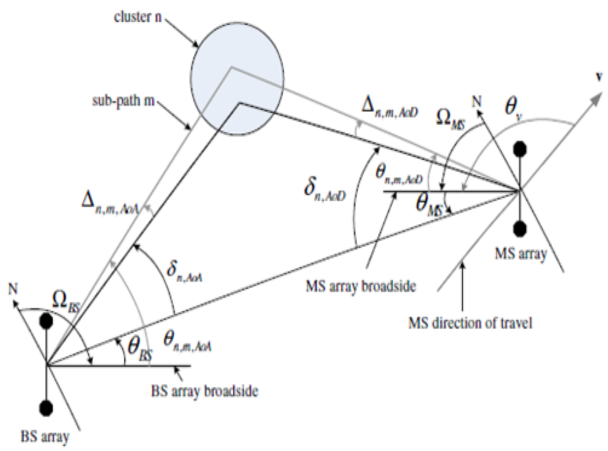


**Figure 2 GBSM Channel Model**


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A channel model of this scenario is shown in Figure 2.

The channel model scenario conditions are given in Table 1.

***Table 1. Channel Scenario Parameters***

| Channel Scenario | Macrocell | Microcell |
|---|---|---|
| Carrier frequency | 5GHz | 5GHz |
| BS antenna spacing $d_T$ | 0.5λ | 0.5λ |
| MS antenna spacing $d_R$ | 0.5λ | 0.5λ |
| N (No of paths) | 1 | 1 |
| M (No of sub-paths) | 20 | 20 |
| Mean Angle at MS | E( $\sigma_{AS}$)=5° | E( $\sigma_{AS}$)=19° |
| $r_{AS}$= $\sigma_{AOD}$ / $\sigma_{AS}$ | 1.2 | Not applicable |
| AS Per path at MS | 2° | 5° |
| MS - AOD | N(0, $\sigma^2_{AOD}$) | N(-40°,40°) |
| Mean Angle at BS | 68° | 68° |
| AS Per path at BS | 35° | 35° |
| BS - AOD | N(0, $\sigma^2_{AOA}$) | N(0, $\sigma^2_{AOA}$) |

## III. CAPACITY OF MASSIVE MIMO WITH COUPLING

The MIMO system capacity for the unknown CSI at the transmitting end is given by

$$C=E[\log_2(\det(I_N+\rho HH^+/N_t))\} \quad (9)$$

Since each pair of antennas are having independent fading path between transmitter and receiver, the channel matrix H also having IID components.

### *Mutual Coupling Model*

In the mutual coupling model, the current in one antenna induces the voltage in the neighboring antennas. The channel with mutual coupling is given below [9].

$$H_{mc}=C_b H C_m \quad (10)$$

where $C_b$ and $C_m$ are the coupling matrixes at the base and mobile stations respectively. The effect of coupling matrix is given by the equation

$$C=(Z_A+Z_T)(Z+Z_T I_N)^{-1} \quad (11)$$

$I_N$ is identity matrix, $Z_T$ is the receive antenna impedance The mutual impedance between the antenna elements is given by Z of size Nt*Nr. Mutual coupling channel model is more practical for massive MIMO. It is helpful to analyze the massive system.

The capacity with mutual coupling between elements is given as

$$C=E\left[\log_2\left(\det\left(I_{Nr}+\zeta H_{mc}H^{+}_{mc}/N\right)\right)\right] \quad (12)$$

## IV. RESULTS AND DISCUSSION

The mean capacity of the MIMO system with large number antenna elements at the receiving side for the IID and realistic channel models are analyzed. Figure 3 shows the capacity in bits/sec/Hz versus number of receive antennas for $N_T$=20, dt=1λ, $L_t$ =20 λ and SNR=15dB. The number of receive antennas are varied from 1 to 50 and the corresponding capacity is plotted for IID channel and realistic channel model with and without mutual coupling, by assuming no correlation between elements. It has been observed that the mutual coupling is high, if the spacing is less than 0.5 λ. So channel capacity decreases with mutual coupling.

The mean capacity in bits/sec/Hz versus number of receive elements ($N_R$) for CBSM channel model is shown in Figure 4. In this, capacity decreases with mutual coupling, but 2D array configuration provides better capacity results.

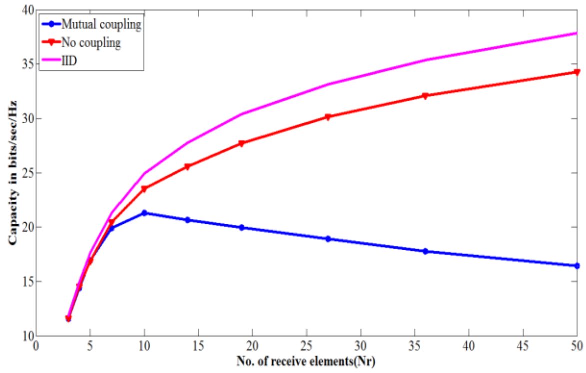


**Figure 3 Mean capacity in terms of NR**

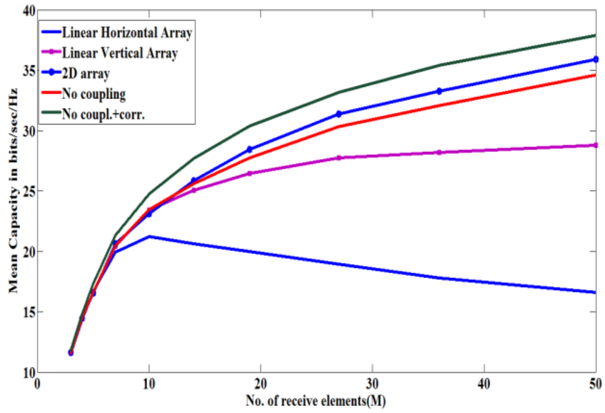


**Figure 4 Mean capacity as a function of NR for CBSM channel model**

Mean capacity of the system using GBSM channel models are analyzed. Here, suburban macrocell and urban microcell propagation scenarios are considered. The simulated capacity of the urban microcell provides better results than suburban macrocell environments.

In the GBSM channel, The channel capacity with mutual coupling for different channel model is evaluated based on Monte Carlo realizations. The mean capacity versus SNR for different channel models are plotted in figure 5. The value SNR is varied from 3 to 12dB.



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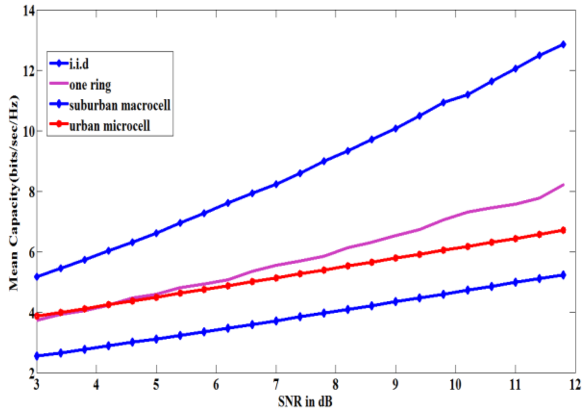


**Figure 5 Mean capacity Versus SNR for GBSM channel models**

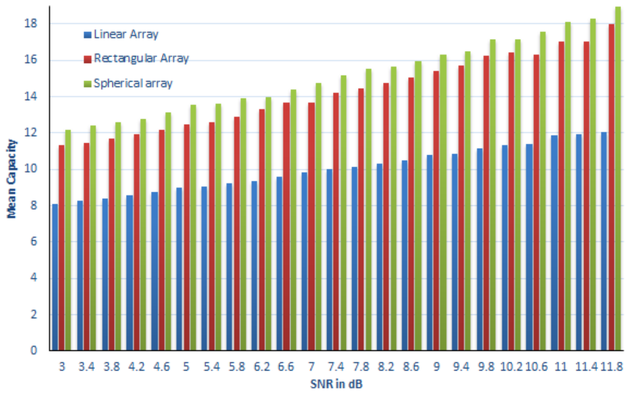


**Figure 6 Mean capacity of different antenna configurations in Microcell channel model**

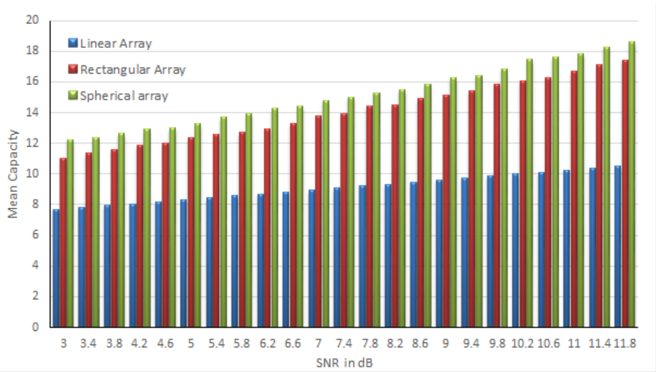


**Figure 7 Mean capacity of different antenna configurations in picocell channel model**

The mean capacity of different antenna configurations are analyzed for GBSM microcell and picocell environments and the results are plotted in Figure 6 and Figure 7. The result shows that two dimensional antenna configurations provide better mean capacity than one dimensional linear array. Two dimensional antenna configurations provide less mutual coupling than the others.

## V. CONCLUSION

The massive MIMO capacity of the 1D and 2D antennas are analyzed for the CBSM and GBSM channel models. CBSM is a theoretical model and it gives better capacity results for 2D array configurations. In the case of GBSM channel models suburban macrocell, urban microcell and picocell channel environments are considered. The channel capacity of linear, rectangular and spherical array antennas are analyzed for the GBSM channel models. It is shown that the 2D antenna arrays of the urban microcell provides higher capacity than suburban macrocell and also it provides better capacity results for the microcell and picocell environments.

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