Effect of Array Geometry on the Capacity of Outdoor MIMO Communication: A Study

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***Abstract*—MIMO systems have gained immense attention in the recent times for supporting high data rates and reliability. Different MIMO channel models have been proposed in the literature. Geometrically based single bounce one ring channel model is a widely used technique for modeling the channel. Evaluation of the performance of the channel has been widely studied under a uniform linear and circular array assumption. Other easily implementable array geometries require to be explored. In this paper four different array geometries each having four elements have been studied.**

***Index Terms*—Antenna arrays, Geometric modeling, MIMO systems**

I. Introduction

THE present day communication is in need for high data rate reliability and better quality of service. Use of antenna arrays contributes toward achieving these goals to a great extent. A system employing multiple antennas at the transmitter and the receiver end is called a multiple-input multiple-output (MIMO) system. A MIMO system exploits both the spatial and temporal domain, thus increasing the degrees of freedom for signal processing. One of the main hindrances in MIMO wireless communication is the channel, which is both space and time dependant. The ergodic capacity of a MIMO wireless communication system in a multipath environment is given in [1]. To find the channel matrix H and its spatial fading correlation analytically, many models have been reported in literature [1]-[3]. One ring channel model [1] is a widely used model for studying outdoor MIMO communication. In this model the scatterers are placed on a ring with the mobile station (MS) placed at its center. Generally, a single scatterer placed on the ring represents a group of scatterers, which are responsible for incident rays from a particular direction. The radius of the ring is determined by the angular spread subtended at the base station in the uplink. Earlier works have mostly been carried out to find the performance of this channel under uniform linear array (ULA) assumption. Although ULA is the widely used array configuration, other geometries also have potential implementation advantages. However these geometries have not been explored to a great extent [7].

In this paper we investigate the effect of different array configurations on the capacity of a MIMO channel, in the backdrop of Geometrically Based Single Bounce (GBSB) model frame work. The variation of the ergodic capacity for different array geometries at the Base Station (BS) and MS has been evaluated through computer simulation, as a function of (a) SNR, (b) separation between the BS and the MS, (c) change in orientation of MS, (d) operating frequencies. Keeping in mind the different geometrical configurations that are considered for investigation, four element arrays have been used. The scatterers are have been kept uniformly distributed. In Section II the Geometrically based single bounce model is described. The simulation results are discussed in Section III. Finally some concluding remarks are given in Section IV.

II. GBSB Model Illustration

Geometrically based single bounce model can be contemplated as a stochastic version of the ray tracing model. The separation between the BS and the MS is assumed to be large enough so that incident waves on the MS from the BS can be considered to be plane waves and ray approximation holds true [4]. It is assumed that a particular ray reaching the MS has been scattered by a single scatterer only. The rays those are scattered by multiple scatterers are neglected as they have very little energy and are comparable with the noise floor level.

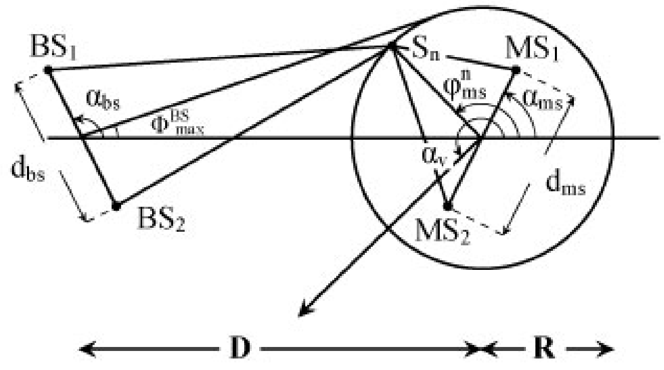

Fig. 1. Geometrically based single bounce one ring model.

It has been shown in [5] that the diffused component of the signal between j^{th} antenna of the transmit array and the i^{th} antenna of the receive array for a ULA can be written as

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$$h_{ij} = \lim_{N\to\infty} \frac{1}{\sqrt{N}} \sum_{n=1}^{N} \exp\left(j\pi \frac{d_{bs}}{\lambda} \left[\cos(\alpha_{bs}) + \phi_{\max}^{bs} \sin(\alpha_{bs}) \sin\left(\phi_n^{ms}\right) \right] \right) \exp\left(j\pi \frac{d_{ms}}{\lambda} \cos\left(\phi_n^{ms} - \alpha_{ms}\right) \right) \quad (1)$$

where, $\phi_{\max}^{bs}$ is the angle spread at the BS, ϕ_n^{ms} is the AOA at the MS from the n^{th} scatterer, N is the number of scatterers surrounding the MS, d_{ms} is the antenna element separation at the MS, d_{bs} is the antenna separation at the BS, λ is wavelength of the signal, α_{bs} and α_{ms} are the angles between the x-axis and the orientation of the BS's and MS's antenna arrays respectively. It has been assumed that the base station is elevated and devoid of scatterers but the mobile station is uniformly surrounded with scatterers.

The above equation is suitably modified for the other array configurations.

A. Capacity of NXN Stochastic MIMO channel

The capacity of an N X N matrix channel corrupted with additive white Gaussian noise can be written as [6]

$$C = \log_2 \det\left[I + \frac{SNR}{N} HH^{\dagger} \right] bits/s/Hz \qquad (2)$$

where N is the number of transmit/receive antennas, SNR is the average receive signal to noise ratio and $\mathbf{I}$ is the identity matrix with dimension $N \times N$. $\mathbf{H}$ is the channel matrix and $\mathbf{H}^{\dagger}$ is the conjugate transpose of the channel transfer matrix $\mathbf{H}$. It is assumed that the transmitted signal vector consists of independent equal power components and the channel state information is available at the receiver. If the elements of the channel matrix $\mathbf{H}$ are known the capacity is calculated from (1). In our study, we have considered four easily implementable array geometries, each having four elements. The array geometries considered are uniform linear array (ULA), uniform circular array (UCA), rhombic array and star array as shown in Fig. 2. With four different array configurations, two arrays taken at a time, one for base station and the other for mobile station, sixteen different configurations are possible. Each of these configurations has been investigated. The minimum antenna separation in the mobile station array has been kept at λ. In the simulation it is assumed that the distance between the BS and the MS is much greater than the radius of the scattering circle which in turn is much greater than the inter element spacing of the antenna arrays. The scatterers are assumed to be uniformly distributed over the ring surrounding the MS and the scattering around base station is neglected.

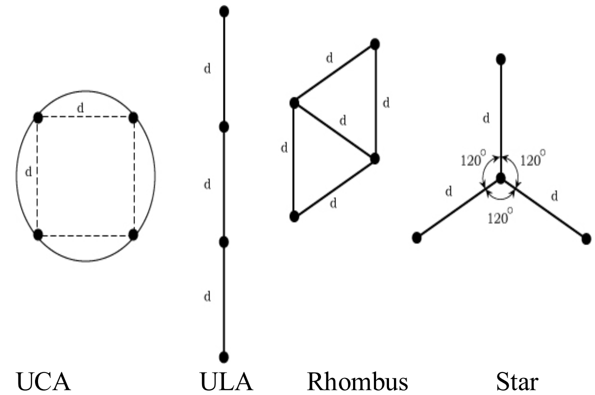

Fig. 2. Geometry of different arrays.

III. SIMULATION RESULTS AND DISCUSSIONS

All simulations were performed using MATLAB®. The distance between the BS and the MS were assumed to be 200λ, 25 scatterers were uniformly distributed on the scatterer ring of radius 53.5λ thus subtending an angular spread of 15^{o} at the BS. The MS is placed at the center of the scattering circle. The BS was assumed to be placed at the origin of the XY coordinate system and the MS on the X axis at a distance of 200λ, without loss of generality. The frequency of operation was taken to be 900 MHz. The SNR was varied form 0 to 35db and the variation of the capacity, over this SNR range, for different antenna configurations were found out and plotted in Fig. 3. It has been found that for linear array geometries both at the BS and the MS gives maximum achievable capacity, with the angle of arrival being (AOA) being uniformly distributed between 0 to 360° at the MS. The variation of the capacity with distance of separation between the BS and the MS for different array geometries were also studied, keeping the SNR value fixed at 15db and is shown in Fig. 4. Table (1) shows the capacity for different array geometry combinations at the BS and the MS at 20 db SNR. The effect of different angular orientation of the MS on the capacity has also been found out and plotted in Fig. 5. It has been observed that the mean capacity is maximum for the combination having linear array at the BS and a star array at the MS. The standard deviation of the capacity is also minimum for this array combination. Fig. 6. shows the effect of frequency on the capacity for some of the array combinations.

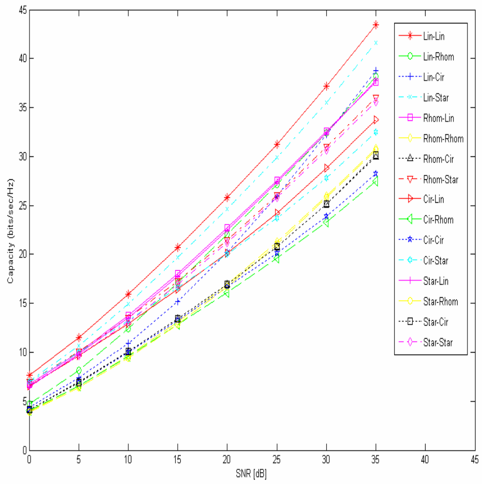

Fig. 3. Plot of SNR Vs Capacity for different array geometries.

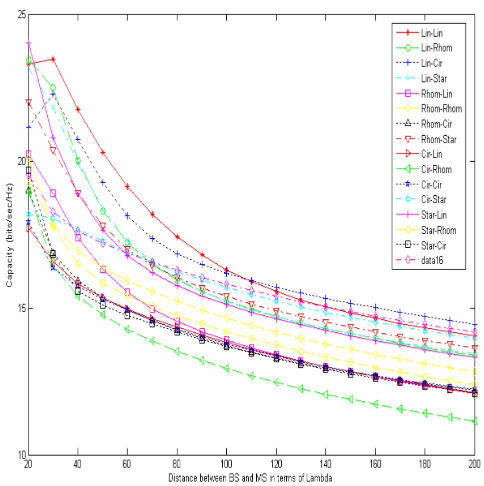

Fig. 4. Plot of the variation of capacity with separation between Tx. And Rx. For different array geometries

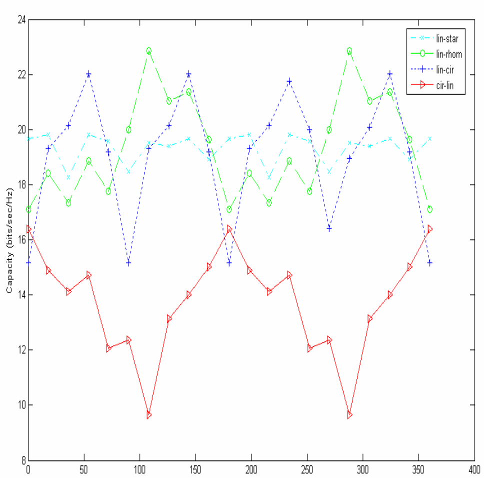

Fig. 5. Plot of the ergodic capacity at different angles of rotation of the MS for different array configurations.

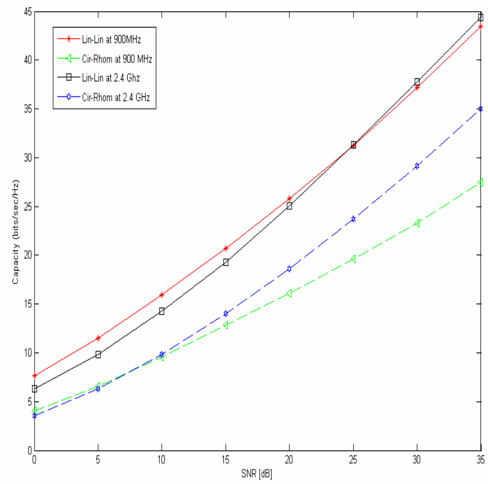

Fig. 6. Plot of ergodic capacity at different frequencies and two different array combination at BS and MS.

TABLE I
CAPACITY FOR DIFFERENT ARRAY GEOMETRY CONFIGURATIONS AT THE BS AND MS AT 20 DB SNR AND 200 λ SEPARATION

MS / BS	Linear	Circular	Rhombus	Star
Linear	**30.1943**	23.4468	23.8656	26.7247
Circular	21.1250	19.4209	20.2942	20.4370
Rhombus	19.1335	21.2836	22.2994	23.3431
Star	22.5420	20.3462	20.2672	21.9323

IV. CONCLUSIONS

In this paper we have investigated the effect of the influence of array geometry on the capacity of MIMO channel simulated under the frame work of one-ring model. We observe that the ULA array geometry at the BS and MS gives maximum capacity but the capacity varies with the rotation of the MS. While the combination of ULA at the BS and the star configuration at the MS gives the maximum achievable mean capacity. As seen the capacity results for different array configurations also vary differently with frequency of operation. The issues highlighted in this paper are to be considered in array design for MIMO system with a given capacity and frequency of operation.

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VI. BIOGRAPHIES

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