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Effect of Radiation Pattern of MIMO Antenna System on the Capacity for Different Channel Models

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A.M.M.A Allam[1,*], Khalid Monir Ahmed[2]

[1] Faculty of Information Engineering and Technology German University in Cairo Cairo, Egypt

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ABSTRACT

The article presents the effect of radiation pattern of MIMO antenna system on the capacity for different channel models. A linear array of MIMO antenna system operating in UWB is deployed in a MATLAB simulation to examine the effect of antenna directivity on channel capacity. The One-ring and Kronecker models are used. On the other hand, mutual coupling between the antenna elements is considered in capacity calculation. A comparison between the capacity for non-directive and directive antennas is studied at different frequencies, which confirms the frequency dependency.

Keywords:
UWB, MIMO, capacity, Kronecker model; radiation pattern, mutual coupling

1. Introduction

The initiation of Multiple-Input Multiple-Output (MIMO) technology in 1970s significantly aided the cause of increasing the communication's capacity. MIMO antenna system increases the channel capacity linearly with number of users in both the transmitter and receiver without the need for extra power or frequency spectrum [1].

Many previous researches [2-4] devoted to study the effect of mutual coupling on system's capacity without considering the effect of radiation pattern of receiving and transmitting antennas. In the following sections, the impact of mutual coupling as well as radiation pattern on system's capacity is investigated applying UWB MIMO antenna to different channel models for capacity calculations.

2. Capacity Estimations

Several studies investigated the effect of channel correlation, antenna correlation and MIMO capacity [2-4]. Yet, paradox claims regarding the impact of mutual coupling on channel capacity is depicted. Ref [2] proclaimed that the mutual coupling has positive influence on capacity performance. While another claim that it degrades the capacity [3]. Some other studies as [4],

* *Corresponding author.*
E-mail address: abdelmegid.allam@guc.edu.eg (A.M.M.A Allam)

claims that the positive impact of mutual coupling is limited for certain cases (e.g. a range of antenna separations). In the following sections, the channel capacity of a system consists of UWB MIMO transmitting and receiving antennas considering the directivity of antennas is evaluated using two channel models; Kronecker and one-ring models.

A. Kronecker Model

The correlation matrices of transmitter and receiver antennas as well as the independent and identically distributed channel matrix Hi.i.d which can be either normal Gaussian or circular symmetric complex Gaussian are all taken into consideration for system's capacity calculation. Channel matrix H is given as [5].

$$\mathrm{H} = \Psi_{\mathrm{R}}^{1/2} \mathrm{H}_{\mathrm{i.i.d.}} \Psi_{\mathrm{T}}^{1/2} \quad (1)$$

where, $\Psi_{\mathrm{R}}^{1/2}$ and $\Psi_{\mathrm{T}}^{1/2}$ are the correlation matrices of both transmitter and receiver. The circular symmetric complex Gaussian matrixes off diagonal elements are identical conducting less diverse channel paths than that of the normal Gaussian.

B. One-Ring Model

In contrary to Kronecker model, the channel capacity estimation in One-ring model doesn't require prior knowledge of antenna correlation matrices. The channel matrix Hmn is given as

$$\mathrm{H}_{\mathrm{mn}} = \frac{1}{\sqrt{\mathrm{L}}} * \sum_{\mathrm{l=1}}^{\mathrm{L}} \alpha_{\mathrm{l}} \exp\left[-\mathrm{j}\frac{2\pi}{\lambda}\left(\mathrm{D}_{\mathrm{ml}} + \mathrm{D}_{\mathrm{ln}}\right)\right] \quad (2)$$

where, L is number of scatterers and $\alpha_{\mathrm{l}}$is the scattering coefficient, which is represented as a normal complex random variable with zero mean and unit variance. Finally, Dml is the distance between mth transmitting antenna and lth scatterer. While, Dln is the distance from lth scatterer and nth receiving antenna [6].

By modifying Shannon capacity calculation formula considering a MxN MIMO system with a complex Gaussian channel matrix H, uniform power allocation to each transmitting antenna and Additive white Gaussian noise, AWGN, at the receiver, the capacity can be depicted as

$$\mathrm{C} = \log_2 \det(\mathrm{I}_{\mathrm{N}} + \frac{\gamma \mathrm{HH}^*}{\mathrm{M}}) \quad (3)$$

where I is an identity matrix of size N, H is MxN channel matrix, * is the complex conjugate and γ is the Signal-to-Noise-Ratio at receiving antennas.

Considering our proposal of involving mutual coupling and radiation pattern in capacity calculation, channel matrix H can be demonstrated as:
H with mutual coupling

$$\mathrm{H} = \mathrm{Z}_{\mathrm{r}}^{-1} * \mathrm{H} * \mathrm{Z}_{\mathrm{t}}^{-1} \quad (4)$$

Kronecker with radiation pattern

$$H = \Psi_R^{\frac{1}{2}}(C_{Tx}.H_{i.i.d.}.C_{Rx}{}^T)\Psi_T^{\frac{1}{2}} \quad (5)$$

One-Ring with radiation pattern

$$H_{mn} = \frac{1}{\sqrt{L}} * \sum_{l=1}^{L} C_{ml}\alpha_l C_{ln} \exp\left[-j\frac{2\pi}{\lambda}\left(D_{ml} + D_{ln}\right)\right] \quad (6)$$

where, Z_r and Z_t are the impedance parameters matrices of the receiver, and the transmitter antenna system respectively, CTx is matrix of MxN normalized values of power distribution associated with angles of departure from M transmitter antennas to N receiver antennas in reference to the radiation patterns and CRx is a matrix of NxM factors of normalized power of the radiation pattern for N receiving antennas. Lastly, Cml is the coefficient of power radiating in the angle of departure from mth transmitting antenna to lth scatterer, while Cln is the coefficient of power radiating referenced to the angle of arrival at the nth receiving antenna from lth scatterer.

3. System design and results

The system's capacity using Kronecker and One-ring channel models is estimated given impedance matrices of the transmitter and receiver antennas in addition to radiation pattern of linear configuration array antenna discussed in previous section. The orientation of array antenna is heavily considered during simulation because of the influence of radiation pattern, so a transmitting array antenna at the base station facing a receiving array antenna at the other end is set in place to run an efficient simulation. It is depicted later and associated with the radiation pattern of each antenna at different frequencies. Two frequencies are selected for the simulation 6 and 10 GHz conducting a various responses affected by antenna directivity. A Matlab code devoted to estimate channel capacity of a scenario shown in Fig.1 where the base station's latitude is fixed at 15 meter while the receiver's latitude varies from l to 15 meter.

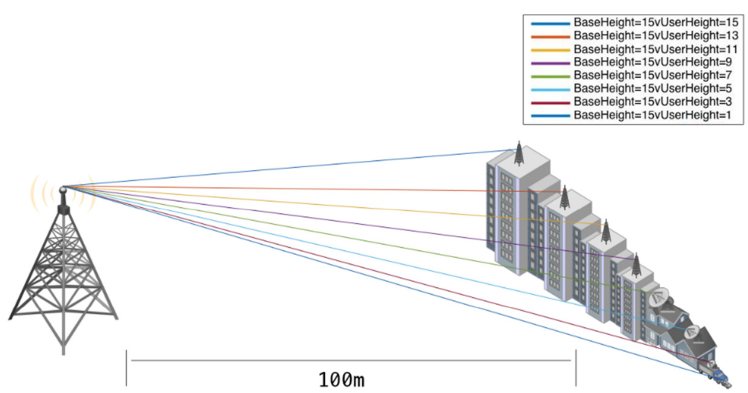

Fig. 1. Simulation scenario

Fig.2 shows the radiation patterns of the transmitting and receiving antennas at frequency 6GHz, which demonstrates the power distribution across the angles of active radiation (e.g. from 0 to 90 and from 270 to 360).

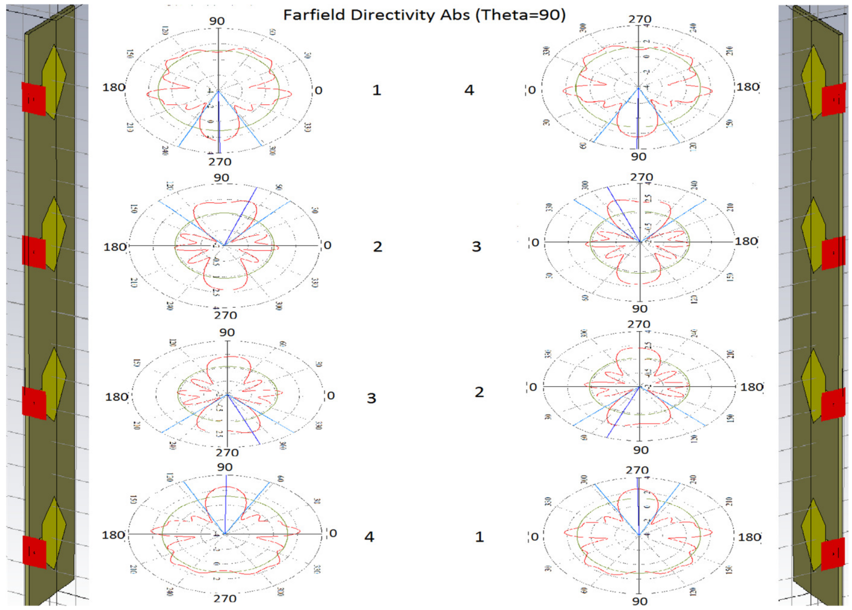

Fig. 2. Orientation and radiation pattern of transmitting and receiving antennas at 6GHz

The average capacity estimated versus SNRs considering directive transmitting and receiving antennas using One-ring and Kronecker is depicted in Fig. 3. The capacity for the case of non-directive antennas is illustrated in red solid line for the sake of comparison. The figure shows the average capacity for a fixed transmitter height at 15 meter and variable receiver heights from 1 to 15 meter. One can notice the relation between latitude and capacity affected by radiation pattern. High latitude receivers provide more capacity than the lower latitude receivers, which is totally dependent on radiation pattern. Furthermore, the directive antennas average capacities show a varying degradation compared to the non-directive one reliant on the used model. One-ring model shows a significant better system's capacity than Kronecker.

At 10GHz the radiation pattern illustrated in Fig. 4 shows a less directive pattern across angles of active radiation resulting in a dramatic reduction of average capacity compared to the non-directive case as shown in Fig.5, which conducts an average capacity of 20 bits/sec, while the average capacity for directive antenna barely exceeds 1.5 bits/sec in the best capacity-producing model, which is the One-ring model.

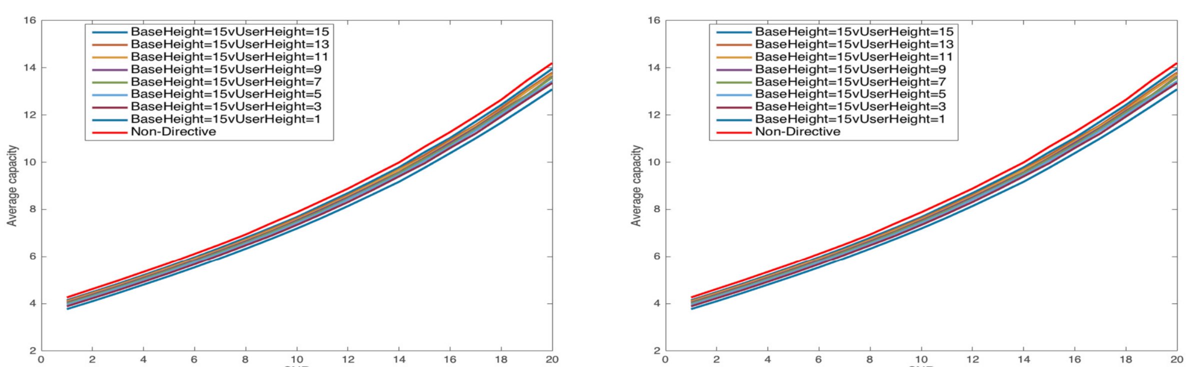

Fig. 3. Capacity estimation at 6 GHz, (left) One-ring model; (right) Kronecker model

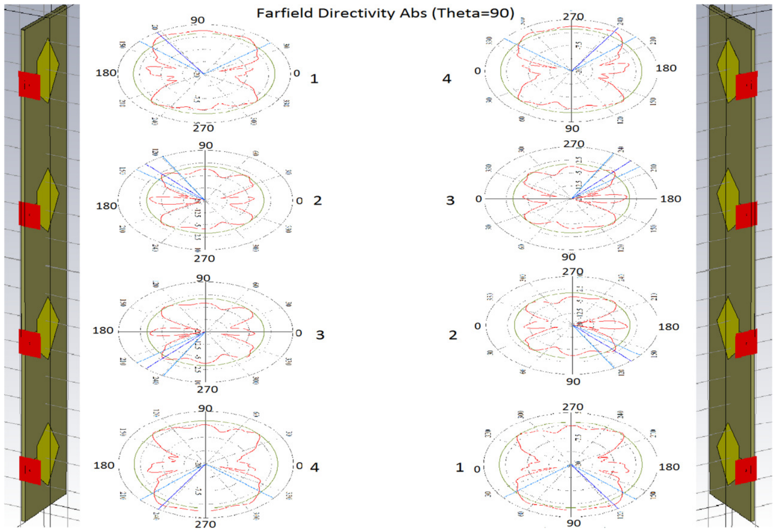

Fig. 4. Orientation and radiation pattern of transmitting and receiving antennas at 10GHz

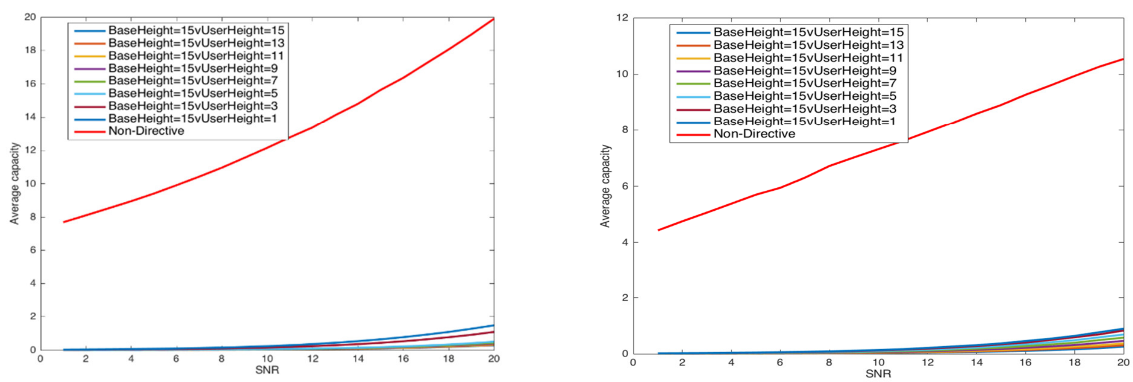

Fig.5 Capacity estimation at 10 GHz in: (left) One-ring model; (right) Kronecker model

4. Conclusion

In this paper, an UWB linear array of pentagon-shaped antennas is deployed to a simulation of various scenarios conducting significant correlation between antenna directivity and capacity. System's average capacity is estimated using One-ring and Kronecker models. There are two main factors that affect the capacity in both models, which are the mutual coupling, and the radiation patterns of the transmitting and receiving antennas. The later is considerably studied at two different frequencies (e.g. 6 and 10 GHz) where each produces different radiation pattern resulting a various degradation of capacity compared to the non-directive antenna case. At 6 GHz the reduction of system's capacity is detected from 14.2 to 13.96 bits/sec in the case of equal latitude of base station and receiver of 15-meter using One-ring model. On the other hand 10 GHz case shows a significant decrease in capacity as it decays from 20 to 1.5 bits/sec .1.5 bits/sec is the peak capacity of the directive antenna, which runs a scenario of transmitter height at 15-meter and receiver height at 1-meter. It demonstrates the effect of radiation pattern's nulls on the average capacity. To conclude, it is safe to presume the deliberate dependency of capacity on frequency.

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