On the performance of adaptive MIMO systems using radiation pattern reconfigurable antennas

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Introduction

In the last few years, Multiple Input Multiple Output (MIMO) applications have been suggested as an effective mean to enhance transmission performances by exploiting multipath scattering effects. These systems use multiple antennas at both receiver and transmitter in order to increase communication capacity. Theoretically, the higher the number of antennas, the better the capacity enhancement. However, their radiation characteristics have also an important impact on the channel capacity [1]. Antenna patterns which offer low signal correlation between each radiating element are suitable for a high channel capacity. Furthermore, since the channel is not stationary, it is interesting that each antenna of the MIMO system can switch between different radiation pattern configurations in order to optimize in real time the channel capacity to prevent environment modifications. So reconfigurable antennas used as one of multiple radiating elements offer an additional degree of freedom for adaptive MIMO communications [2].

This paper presents a MIMO channel model which takes into account the antenna radiation patterns in a 4π steradians range. Polarizations along θ and ϕ are both considered. Capacity performances are calculated from the channel matrix determined with the model. Antennas used in the simulation are reconfigurable cubic antennas, previously presented [3].

Adaptive MIMO principle

Achievable MIMO capacity strongly depends on the channel matrix. Indeed, the capacity can be determined with the following expression

$$C = log_2(det[I + \frac{SNR}{M} HH^H]) \quad (1)$$

where H represents the channel matrix, SNR the Signal to Noise Ratio, I the identity matrix and M the number of transmission antennas. Since the matrix H includes antenna radiation properties, it is possible to maximize the channel capacity by choosing appropriate radiation patterns. However, most of the time, the environment is not stationary. So antenna properties have to be readjusted depending on the H matrix evolution. Pattern reconfigurable antennas find here a great interest. Instead of using adaptive antennas like antenna arrays which requires a large number of elements and a complex control command, this paper study the use of pattern reconfigurable antennas which have only a small number of radiation configurations. By switching pattern configurations of each antenna composing the

MIMO system, several H matrix are so available. By estimating the channel for each configuration, during a training sequence for example, antenna configurations which offer the best capacity are then chosen.

Channel model

Let's consider a MIMO system with M transmission antennas and N reception antennas. By considering the microwave propagation along ϕ and θ, the channel matrix H can be written as

$$H = \begin{bmatrix} h_{\theta\theta_{11}} + h_{\phi\phi_{11}} & h_{\theta\theta_{12}} + h_{\phi\phi_{12}} & \cdots & h_{\theta\theta_{1M}} + h_{\phi\phi_{1M}} \\ h_{\theta\theta_{21}} + h_{\phi\phi_{21}} & \cdots & \cdots & \vdots \\ \vdots & \cdots & \cdots & \vdots \\ h_{\theta\theta_{N1}} + h_{\phi\phi_{N1}} & \cdots & \cdots & h_{\theta\theta_{NM}} + h_{\phi\phi_{NM}} \end{bmatrix} \tag{2}$$

with coefficients defined as

$$h_{\theta\theta_{ij}} = \sum_{p=0}^{L} E^{(p)}_{\theta_{TX_i}} . \alpha^{(p)}_{\theta} . e^{j(\overrightarrow{k}^{(p)}_{TX} . \overrightarrow{r}_{TX_j} + \overrightarrow{k}^{(p)}_{RX} . \overrightarrow{r}_{RX_i})} . E^{(p)}_{\theta_{RX_j}} \tag{3}$$

$$h_{\phi\phi_{ij}} = \sum_{p=0}^{L} E^{(p)}_{\phi_{TX_i}} . \alpha^{(p)}_{\phi} . e^{j(\overrightarrow{k}^{(p)}_{TX} . \overrightarrow{r}_{TX_j} + \overrightarrow{k}^{(p)}_{RX} . \overrightarrow{r}_{RX_i})} . E^{(p)}_{\phi RX_j} \tag{4}$$

where E represents the radiated complex electric field component along ϕ or θ of the i^{th} transmission (TX) antenna or the j^{th} reception (RX) antenna. $\overrightarrow{k}_{TX}$ and $\overrightarrow{k}_{RX}$ are waveguide numbers ($|k| = \frac{2\pi}{\lambda_0}$) of the propagated field along the path p at the transmission and at the reception respectively. $\overrightarrow{r}$ is the vector which indicates the location of the considered antenna. α is the complex attenuation modeling the environment propagation. Propagation along ϕ and propagation along θ are supposed uncorrelated. So α_ϕ and α_θ are uncorrelated and are determinate by a Rayleigh law. For each coefficient, L paths p are considered. Angles (ϕ and θ) of departure and arrival of each path p follow a Laplacian distribution. The matrix H is then normalized using the Frobenius norm in order to calculate the channel capacity with the equation (1).

Considered reconfigurable antennas

The pattern reconfigurable antenna considered in this paper is shown on figure 1. It is a cubic cavity which radiates through six rectangular slots [3]. The feeding is achieved by a probe which penetrates the cube by one of its corner. PIN diodes have been located in the middle of each slot as the picture on figure 2 shows it. So, by controlling diodes states, it is possible to cancel or not the radiation of slots. If a diode is in ON state, the corresponding slot is short-circuited and its

contribution to the antenna radiation is neglected. However, if a diode is in OFF state (open circuit), the slot can radiate. By controlling independently each diode, so each slot radiation, radiation pattern reconfiguration can be achieved. In this paper, three pattern configurations are considered. Each configuration contains three radiated slots and three short-circuited slots. Configurations are symmetrical around the feeding probe. Thus, the antenna return loss is not affected by the change of configuration. Radiation patterns in each configuration have been measured in a 4π steradians range along both polarizations ϕ and θ in a near-field anechoic chamber. Results are given on figure 3.

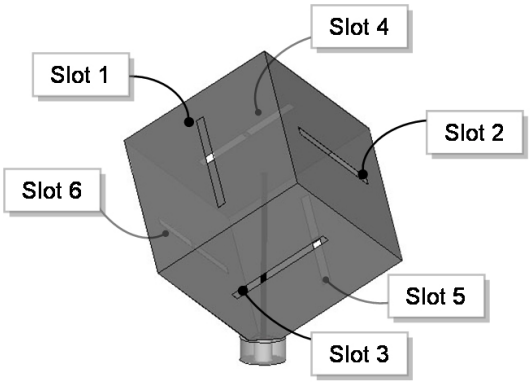


Figure 1: Schematic drawing of the reconfigurable cubic antenna.

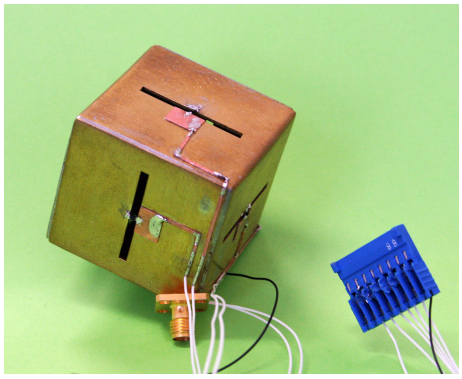


Figure 2: Reconfigurable cubic antenna with PIN diodes.

Capacity results

A 2x2 MIMO transmission is considered. We assume that the pattern reconfiguration is only available at the reception (figure 4). Transmission antennas are supposed isotropic along ϕ and θ. Each reception antenna has three pattern configurations. So, for each channel iteration, $3^2 = 9$ matrices H are available. Reconfigurable antennas are supposed surrounded with many scatterers which is traduced in the simulation by a large angular spread ($\sigma_{RX} \simeq 360°$). Isotropic antennas are supposed far from the scattering area, so $\sigma_{RX} \simeq 20°$. $L = 20$ paths are considered. The cumulative mean capacity is plotted on figure 5 for all available pattern configurations. Distance between RX antennas is about 10 mm (operating frequency about 5 GHz). The three lower curves represent the capacity with both RX antennas having the same pattern configuration (spatial diversity only). The six curves in the middle represent the capacity with RX antennas in different configurations. The capacity is higher than in previous curves because in this case, the spatial diversity is combined with the radiation diversity. For each channel iteration, the best radiation configuration has been saved and the result is shown by the higher curve (optimal case). A 20 % capacity enhancement has been achieved using the pattern reconfiguration.

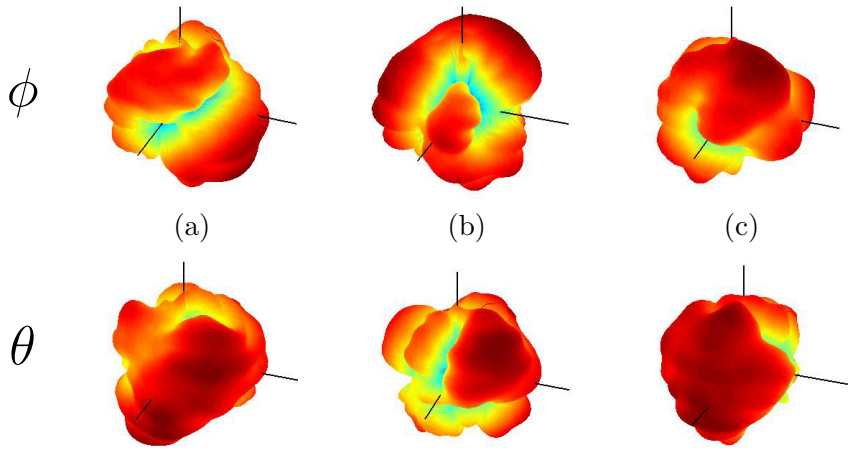


Figure 3: Measured radiation patterns along ϕ and θ for (a) configuration n°1, (b) configuration n°2, (c) configuration n°3.

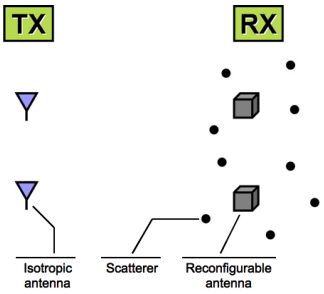


Figure 4: 2x2 MIMO transmission scheme.

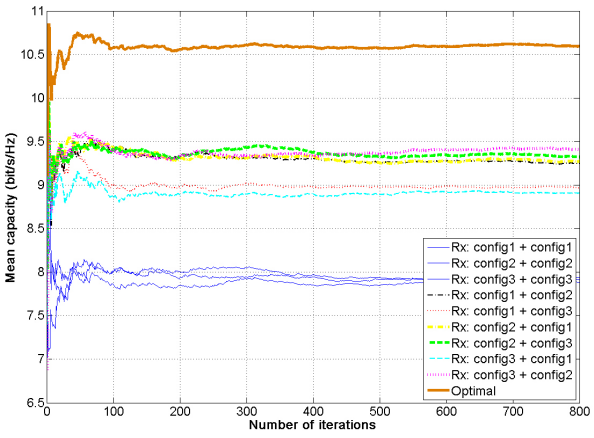


Figure 5: Simulated mean capacity.

References

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