MIMO Communication System with Reconfigurable Circular Patch Antennas

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Introduction

Recent advances in Multiple Input Multiple Output (MIMO) systems have shown that multi element reconfigurable antennas can improve the throughput and the robustness of the wireless communication link [1]. Efficient use of these antennas in MIMO systems has been shown to be a challenging task, still unexplored [2]. The only proposed solution to date for configuration selection [2] is to estimate the transfer channel matrix for every possible antenna configuration and select the one that offers the highest capacity gain. However, estimating the channel response for each antenna configuration at the transmitter and at the receiver has been demonstrated to be power consuming and to have a detrimental effect on the performance of the reconfigurable MIMO system [2].

We propose an alternative receiver configuration selection algorithm that only uses spatial correlation information from a single antenna configuration. By estimating the channel second order statistics for a single antenna configuration we can exploit the gain offered by a reconfigurable MIMO system without any extra power consumption and modifications to the data frame relative to a MIMO system equipped with conventional antennas. We present this configuration selection approach studying the performance of a reconfigurable circular patch antenna (RCPA) in a 2×2 MIMO system. Through a realistic clustered channel model [3], we show that the configuration selection of the reconfigurable circular patch antenna is directly linked to the spatial characteristics of the wireless channel.

Reconfigurable Circular Patch Antenna

In this paper, we present a RCPA similar to the one presented in [4]. The design has been changed to add additional levels of reconfigurability. As depicted in Fig.1, the antenna consists of MEMS switches located radially on the antenna structure that can be turned on and off to achieve a circular patch with three different radii. The antenna is built on a RT/duroid 5880 substrate of dielectric constant equal to 2.2 and each antenna acts as a two element array. There are two feed points on the antenna structure, separated such that the radiation patterns excited at the two ports are orthogonal one to the other. Toggling the switches located radially on the antenna it is possible to vary the current distribution on the antenna structure and excite different TM electromagnetic modes, each corresponding to a particular shape of radiation pattern. The antenna design depicted in Fig.1 allows to select among three different configurations: TM_{12} , TM_{13} and TM_{14} . When all the switches are off, the mode TM_{12} is excited at both ports of the antenna (configuration TM_{12});

Figure 1: (a) Schematic of the reconfigurable circular patch antenna and (b) MEMS switches s_1 and s_2 membrane layouts [5].

Figure 2: Radiation patterns excited in the azimuthal plane at the two ports of the RCPA for all the antenna configurations.

when the only switches s_1 are turned on the mode TM_{13} is excited at both ports of the antenna (configuration TM_{13}); when all the switches are turned on (s_1 and s_2) the mode TM_{14} is excited at both ports of the antenna (configuration TM_{14}). Note that the DC bias is provided directly through the feed points, using a bias-T network, and that the switches s_1 can be activated independently from the switches s_2 since they require a lower actuation voltage with respect to the switches s_2 . The antenna radiation characteristics have been simulated using HFSS including the model of MEMS switches like the one presented in [5]. The RCPA has been designed to operate at 5.2 GHz, though a proper reconfigurable matching network need to be included in the design to have both ports matched at the same frequency of operation for all the antenna configurations. The radiation patterns excited at the two ports of the antenna are depicted in Fig. 2 for all the antenna configurations.

RCPA configuration selection

The RCPA depicted in Fig.1 is used in a 2×2 MIMO system that adopts a spatial multiplexing (SM) transmission scheme. We describe the wireless channel according to the cluster channel model presented in [3]. According to this model, as described in [1], we can define the spatial correlation between the k -th and m -th pattern

Figure 3: (a) Channel capacity curves for three different antenna configurations (TM_{12} , TM_{13} and TM_{14}) in function of the angle spread (AS) for a 2×2 MIMO system employing the RCPA at the receiver; (b) reciprocal condition number, D_λ , in function of the angle spread for the antenna configuration TM_{12} at the receiver.

configuration excited at the j -th and l -th ports of multi element antennas as:

$$r_{j,k,l,m} = \sqrt{(1 - |S_{11j}|^2)\eta_{j,k}(1 - |S_{11l}|^2)\eta_{l,m}} \times \frac{\int_{4\pi} P(\Omega) \underline{E}_{j,k}(\Omega) \underline{E}_{l,m}^*(\Omega) d\Omega}{\int_{4\pi} P(\Omega) |\underline{E}_{ref}(\Omega)|^2 d\Omega} \quad (1)$$

where S_{11} is the voltage reflection coefficients at the antenna input ports, η is the antenna radiation efficiency, $P(\Omega)$ is the power angular spectrum (PAS) of the scattered electric field over the solid angle $\Omega = (\phi, \theta)$, $\underline{E}(\Omega)$ is the electric field of each array element and $\underline{E}_{ref}(\Omega)$ is the electric field of a reference antenna configuration that is used as normalization factor for the spatial correlation coefficient. As in [3] we assume a power angular spectrum that is Laplacian distributed. Knowing the spatial correlation coefficient it is possible to determine the ergodic channel capacity achievable for each antenna configuration of the RCPA, as [1]:

$$C \leq \log_2 \left[\sum_{k=0}^{N_{min}} \left(\frac{SNR}{N_t} \right)^k k! \sum_{1 \leq i_1 < i_2 \dots < i_k \leq N_t} |\mathbf{R}_{t_{i_1, \dots, i_k}}^{i_1, \dots, i_k}| \sum_{1 \leq i_1 < i_2 \dots < i_k \leq N_r} |\mathbf{R}_{r_{i_1, \dots, i_k}}^{i_1, \dots, i_k}| \right] \quad (2)$$

where $N_{min} = \min(N_r, N_t)$, with N_r and N_t being the number of receiving and transmitting elements respectively. $\mathbf{R}_t$ and $\mathbf{R}_r$ are the spatial correlation matrices at the transmitter and at the receiver and $|\mathbf{R}_{t_{i_1, \dots, i_k}}^{i_1, \dots, i_k}|$, $|\mathbf{R}_{r_{i_1, \dots, i_k}}^{i_1, \dots, i_k}|$ are the minor determinants of $\mathbf{R}_t$ and $\mathbf{R}_r$. In this paper we consider only single sided correlated MIMO channels and in particular we use the RCPA at the only receiver while at the transmitter we assume $\mathbf{R}_t = \mathbf{I}$. In Fig.3(a) the averaged channel capacity achievable for all the configurations of the RCPA is reported as a function of the angle spread (AS) of the PAS, for a SNR = 15 dB. The ergodic channel capacity values are averaged over all azimuthal angles of the incoming PAS. We observe that the achievable averaged channel capacity varies as a function of the PAS angle spread. In particular each antenna configuration outperforms the others for a certain range of angle spread. It is therefore possible to select the RCPA configuration at the receiver based on PAS angle spread knowledge.

In order to discriminate between different channel scenarios, characterized by different AS, we can use, as reported in [6], the reciprocal condition number of the transmit/receive correlation matrices, defined as:

$$D_{\lambda} = \frac{\lambda_{max}}{\lambda_{min}} \quad (3)$$

where λ_{max} and λ_{min} are the maximum and the minimum eigenvalues of the transmit/receive correlation matrices. In Fig.3(b) the values of D_{λ} are reported as a function of AS for configuration TM_{12} of the RCPA. For each value of AS, there is a corresponding value of D_{λ} . We can therefore map the values of AS that define a switching point between two configurations with those of the reciprocal condition number. According to this channel parametrization, the wireless channel scenario can be identified determining the spatial correlation matrix at the receiver for a single reference antenna configuration of the RCPA (e.g. TM_{12}). Knowing the channel characteristics it is then possible to select the antenna configuration that achieves on average the highest capacity, using the pre-computed results presented in Fig.3(a).

Conclusions

We have presented a MIMO system, equipped with MEMS reconfigurable circular patch antennas, that allows to select the antenna configuration at the receiver without the need for estimating the wireless channel for each configuration of the reconfigurable multi element antenna. Simulated results have shown that this antenna selection approach is an effective technique suitable for efficiently using pattern reconfigurable antennas in MIMO systems.

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