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EXPERIMENTAL VALIDATION OF SMART ANTENNA SYSTEM
MODEL

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Introduction

In the last decade, the need of effective mobile communication devices has favored the development of wireless technologies. Nowadays, the demand of dealing with complex communication scenarios characterized by multiple users and standards fosters the study of systems able to provide a suitable quality of service (QoS) and an enhanced security [1]. In such a framework, smart antennas have been recognized as promising tools for an efficient management of the physical layer. As a matter of fact, these systems are aimed at maximizing the signal-to-interference-plus-noise ratio (*SINR*) at the receiver by steering the main lobe of the beam pattern to track the desired signals and placing attenuations to cancel the interferences. With respect to standard solutions, smart antennas allow to increase the channel capacity and the service coverage [2].

Although the effectiveness of a hardware implementation has been theoretically proved, the technological difficulties and costs for the implementation of fully-adaptive solutions prevented up till now the application of smart antennas in wireless communications. Some prototypes have been implemented making use of complex acquisition systems, where the signal is collected at the receiver and at the output of the array elements in order to compute the co-variance matrix [3]. On the other hand, simpler fully-adaptive systems based on the measurement of the received signal at the receiver have been also implemented [4]. In both cases, the effectiveness of the implementation has been assessed by comparing measured and simulated radiation patterns in correspondence with a single interferer incoming from a fixed direction. Recently, a smart antenna prototype characterized by a simple functional scheme has been proposed in [5]. In this implementation, the signals collected by the array elements are suitably weighted by the hardware control unit according to an iterative strategy based on the Particle Swarm Optimizer (PSO) in order to maximize a suitable fitness function. The antenna has been preliminarily validated by considering both the behavior of the *SINR* in a complex scenario and the capability of placing nulls in suitable positions of the radiation pattern. In addition, the measured quantities have been compared with the simulations provided by a simple system model [6].

In order to take into account the complexity of the hardware implementation, this paper proposes an innovative model of the adaptive system based on the

integration of the strategy proposed in [6] with a suitable fitness function. After presenting the mathematical formulation, the proposed approach is validated by considering real data collected in an experiment modeling a complex interference scenario.

Mathematical Formulation of the System Model

Let us consider an adaptive array of M non-ideal radiating devices. At the l -th time step ($l = 1, \dots, L$), the m -th element ($m = 1, \dots, M$) is located at the position $\{x_m, y_m, z_m\}$ and receives a narrowband signal $s_m(l)$ expressed as

$$s_m(l) = E_m(\theta, \phi) \gamma(l) e^{j(2\pi fl + \varphi_m)} \quad (1)$$

where $\gamma(l)$ is the slowly varying envelope and f is the carrier frequency. Moreover, $\varphi_m = 2\pi(x_m \sin \theta \cos \phi + y_m \sin \theta \sin \phi + z_m \cos \theta)/\lambda$ is the phase term of the received signal coming from the angular coordinates $\{\theta, \phi\}$ and $E_m(\theta, \phi)$ is the normalized electric field (E-field) pattern of the m -th element. The E-field pattern of the m -th non-ideal radiating device can be evaluated through an electromagnetic simulator or experimentally by turning off the p -th element of the array, $p = 1, \dots, m-1, m+1, \dots, M$. $E_m(\theta, \phi)$ takes into account the mutual coupling effects due to nearby elements and to the other parts of the antenna (e.g., a reflecting plane).

Under the assumption of co-channel interferences, $s_m(l)$ is the result of the sum of a desired signal $d_m(l)$, a set of J jamming signals $i_{j,m}(l)$, $j = 1, \dots, J$, and a background noise contribution $n_m(l)$. As a consequence, the signal $u(l)$ available at the output of the adaptive array is

$$u(l) = \sum_{m=1}^M w_m s_m(l) = \sum_{m=1}^M w_m \left[d_m(l) + \sum_{j=1}^J i_{j,m}(l) + n_m(l) \right] \quad (2)$$

where $w_m = \alpha_m e^{j\beta_m}$ is the m -th complex weight. Therefore, the total output power $\Omega_i(l)$ at the receiver is the sum of the power of the desired signal, Ω_d , of the power of the interferences, $\Omega_i(l)$, and of the noise power, Ω_n . According to [7], Ω_d and Ω_i can be defined as

$$\Omega_d = \frac{1}{2} a_d^2 \left| \sum_{m=1}^M w_m E_m(\theta_d, \phi_d) h_m(\theta_d, \phi_d) \right|^2 \quad (3)$$

and

$$\Omega_i(l) = \frac{1}{2} a_i^2 \sum_{j=1}^J \left| \sum_{m=1}^M w_m E_m(\theta_j, \phi_j) h_m(\theta_j, \phi_j) \right|^2, \quad (4)$$

respectively, (θ_d, ϕ_d) being the direction of arrival of the desired signal and (θ_j, ϕ_j) being the angular direction of the j -th interference, $j = 1, \dots, J$, at the l -th time step. Moreover, $h_m(\theta, \phi) = e^{j\varphi_m(\theta, \phi)}$, $a_d^2 = \text{Exp}\{\gamma_d(l)e^{j2\pi fl}\}$, and $a_i^2 = \text{Exp}\{\gamma_i(l)e^{j2\pi fl}\}$ by assuming equal power jammers. As regards to the noise power, it is equal to $\Omega_n = M\sigma_n^2$, σ_n^2 being the variance of the uncorrelated noise. In order to maximize the *SINR* at the receiver, the optimal set of weights $\underline{w}_{opt} = \{w_m^{opt}; m = 1, \dots, M\}$ is found by solving through the PSOM [6] the optimization problem $\underline{w}_{opt} = \arg\{\min_{\underline{w}}[\Psi_l(\underline{w})]\}$ with

$$\Psi_l(\underline{w}) = \frac{\left| \sum_{m=1}^M w_m E_m(\theta_d, \phi_d) h_m(\theta_d, \phi_d) \right|}{\Omega_l(l)}. \quad (5)$$

It can be shown that the fitness function (5) has a maximum for the same weights vector that maximizes the *SINR* [7].

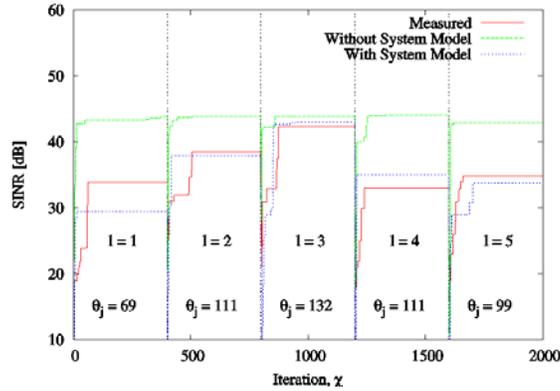


Figure 1 – Behavior of the *SINR* versus the iteration index.

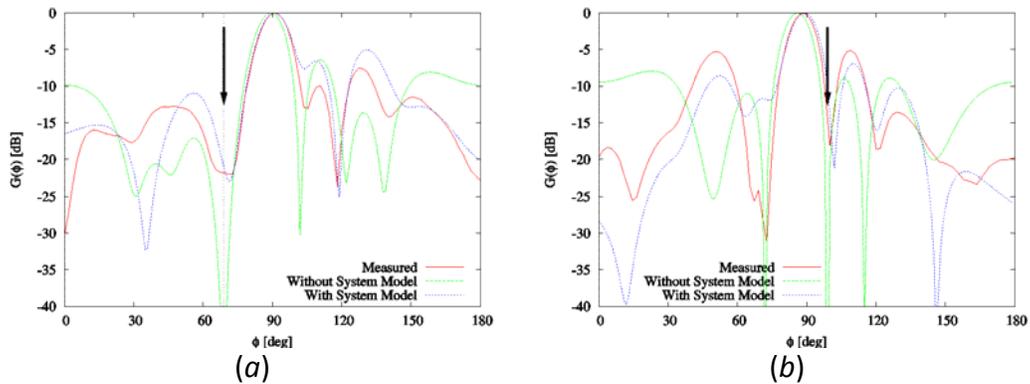


Figure 2 – Beam pattern synthesized at the time steps (a) $l = 1$ and (b) $l = 5$.

Experimental Validation

In order to preliminarily assess the proposed system model, a realistic scenario characterized by $L = 5$ time steps has been considered. The antenna is an adaptive array of $M = 8$ printed dipoles with reflecting plane [5]. In the l -th time step, a jammer impinges on the adaptive array according to the angular direction ϕ_j , as reported in Fig. 1 ($\theta_j = 90^\circ, \forall l$). The optimal weights configuration has been looked for by running the PSOM for $K = 400$ iterations. Figure 1 shows the behavior of the $SINR(\chi) = \Omega_d(\chi) / [\Omega_i(\chi) + \Omega_n(\chi)]$ versus the iteration index $\chi = \sum_{l=1}^L \sum_{k=1}^K k_l$, evaluated with the system model (i.e., with E_m computed through HFSS) and without (i.e., assuming isotropic E_m). The simulated behaviors have been also compared to the $SINR$ obtained by the prototype [5] by assuming the same scenario. The $SINR$ simulated by using the system model appears to be much closer to measured data than the one obtained as in [6]. Furthermore, the behavior of the prototype appears to be better reproduced by considering the mutual coupling effects also when comparing two samples of radiation patterns obtained at the end of the steps $l = 1$ and $l = 5$ (Fig. 2).

Conclusions

In this paper, an innovative model of a smart antenna taking into account the mutual coupling effects has been presented. In the proposed strategy, the fitness function and the $SINR$ are defined by taking into account the non-ideal E-field patterns of the array elements. The preliminary experimental validation pointed out that the system model reproduces the behavior of a smart antenna prototype with a satisfactory degree of accuracy.

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