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OPTIMUM CONSTRAINED BEAMFORMING USING LINEAR MICROSTRIP-PATCH ANTENNA ARRAYS

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1 Introduction

The development of future mobile communication systems is characterized by an increasing demand for heterogeneous broadband services for a large number of users. Thereby the main challenges are provided by the limited spectrum resources as well as the characteristics of the mobile radio channel. In order to cope with this problems the usage of smart antennas is planned which leads to an increased system capacity. Smart antennas provide a technique for increasing the system capacity in different ways. By means of spatial separation the same spectrum resource can be assigned to different users (SDMA, space division multiple access). A further approach is to reduce interferences from multi-path propagation, multi-user access and from other mobile communication systems by spatial filtering for interference reduction (SFIR). The performance increase to be expected when using smart antennas highly depends on how accurate the interferences can be reduces while the signal of interest is received with a maximum gain.

In order to produce smart antennas in a very cost effective way one generally aims at using microstrip patch antenna arrays where the elements are printed on a joint substrate. Using digital beamforming algorithms to generate a beampattern based on a previous estimation of directions of arrival, it is very important to consider the special properties of these arrays in order to steer an optimum beam. Thereby the main challenges are the mutual coupling effects between the elements and especially the coupling effects at the border of the substrate.

In this paper we present the implementation of a blind beamforming algorithm using a microstrip-patch array with eight antenna elements. This beamformer allows optimum beamsteering and interference cancellation for arbitrarily spaced directions of signals of interest as well as for a certain number of interfering signals [1]. The elimination of mutual coupling effects and the necessity of array calibration are shown in this paper.

2 Array Signal Model

The derivation of the array signal model is made from the signal processing point of view. Let us consider a set of L waveforms

$$u_l(t) = a_l(t) \cdot e^{j(2\pi f_c t + \phi_l(t))} = s_l(t) \cdot e^{j2\pi f_c t} \ , \ 1 \leq l \leq L \ , \tag{1}$$

with carrier $e^{j2\pi f_c t}$ and complex baseband signal $s_l(t) = a_l(t) \cdot e^{j\phi_l(t)}$, impinging on an array of M spatially distributed identical sensors. It is commonly assumed that the narrowband signal variations can be neglected as the wavefront passes along the array: $s(t - \Delta\tau_{max}) \approx s(t)$, where $\Delta\tau_{max}$ is the maximum propagation delay. The output signal of the m-th sensor is then given as

$$x_m(t) = \sum_{l=1}^{L} s_l(t) \cdot g_m(\psi_l, \theta_l) \cdot e^{j2\pi f_c(t - \tau_m(\psi_l, \theta_l))} + n_m(t) \ , \ 1 \leq m \leq M \ , \tag{2}$$

with $g_m(\cdot)$ as element pattern and $n_m(t)$ being a noise component of the m-th element with zero mean and variance σ_n^2. In practice each antenna element has a particular pattern $g_m(\cdot)$ which is different from each of the other elements. This phenomenon can be described by mutual coupling effects between the elements and by coupling effects to the border of the substrate, the attachment of the array, the chassis, and other metal components. Without loosing generality, we'll confine the signals to the elevations plane defined by $\psi = \pi/2$. It is convenient to introduce the array steering vector $\boldsymbol{\alpha}(\theta)$ which describes the array response to a signal of frequency f_c from angle of arrival θ

$$\mathbf{x}(t) = \sum_{l=1}^{L} s_l(t) \cdot e^{j2\pi f_c t} \cdot \boldsymbol{\alpha}(\theta_l) \text{ , with} \tag{3}$$

$$\boldsymbol{\alpha}(\theta) = \left[g_1(\theta) \cdot e^{-j2\pi f_c \tau_1(\theta)} \text{ , } g_2(\theta) \cdot e^{-j2\pi f_c \tau_2(\theta)} \text{ , } \dots \text{ , } g_M(\theta) \cdot e^{-j2\pi f_c \tau_M(\theta)} \right]^T . \tag{4}$$

These signals are weighted and combined in order to produce the output signal

$$y(t) = \sum_{m=1}^{M} w_m \cdot x_m(t) = \mathbf{w}^H \cdot \mathbf{x}(t) \text{ ,} \tag{5}$$

where $\mathbf{w} = [w_1 \; w_2 \dots w_M]^T$ is the vector of weights. Clearly, for a fixed set of weights, $y(t)$ is

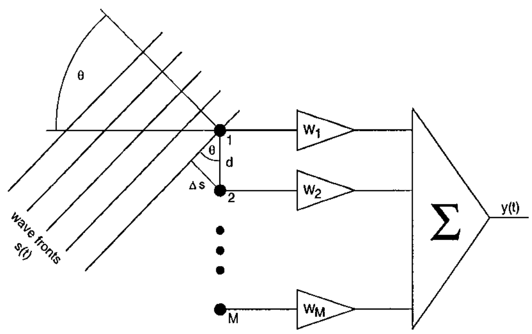

Figure 1: Impinging wave front at an M-element linear array

a function of the incident angle θ. Figure 1 shows a uniform linear array (ULA) of M elements with spacing $d = \lambda/2$. The transfer function or beampattern of this array is defined as

$$H(\theta) = \sum_{m=1}^{M} w_m \cdot g_m(\theta) \cdot e^{-j(m-1)kd\sin(\theta)} = \mathbf{w}^H \cdot \boldsymbol{\alpha}(\theta) \text{ ,} \tag{6}$$

with $k = 2\pi/\lambda$ being the wave number. Now the beamformer has to determine a weight vector, that the beampattern will provide a maximum performance increase.

3 Constrained Beamforming

Beams can be adapted according to different performance measures [2]. Adapting the weights w_m of a smart antenna results in spatial filtering, which effectively increase the signal to noise and interference ratio. In [1] an optimum beamforming algorithm for ideal antenna arrays was developed, which allows optimum beamsteering and interference cancellation for arbitrarily spaced directions of signals of interest as well as for interfering waveforms. In order to generate an optimum beam pattern with real antenna arrays, the beamformer has to consider the special properties of the used array, which means the array must be calibrated. The calibration of an antenna array can be made by different methods. In [3] the differences of the individual element-pattern are described in terms of coupling effects between the antenna elements. Further coupling

effects especially to the border of the substrate cannot be considered. A further calibration method determines the arrays steering vector for a large number of directions of arrival, which are described in terms of the array-manifold. In this case the element pattern $g_m(\cdot)$ of each antenna element is known and can be used for beamforming.
In order to achieve a maximum performance increase the main lobe of the beampattern has to be steered in direction θ_L of the desired signal and cancels signals propagating from directions θ_l with a null, while maintaining maximum directivity. The constraints of the beamformer can be described by

$$H(\theta_l) = \begin{cases} 1 & l = L \\ 0 & l = 1, \ldots, L-1 \end{cases} , \tag{7}$$

with $L \leq M$. A beam pattern $H(\theta)$ which satisfies the constraints, is constructed by setting up a basic function which is similar to a simple phased array

$$Q(\theta, \theta_l) = \sum_{m=1}^{M} g_m(\theta_l) g_m(\theta) \cdot e^{-j\pi(m-1)(\sin\theta - \sin\theta_l)} = \boldsymbol{\alpha}^H(\theta_l) \cdot \boldsymbol{\alpha}(\theta) . \tag{8}$$

With $L-1$ nulls $\theta_1 \ldots \theta_{L-1}$ and the main beam direction θ_L the general beampattern is formed by a superposition of L weighted basic functions

$$H(\theta) = \sum_{l=1}^{L} b_l \cdot Q(\theta, \theta_l) . \tag{9}$$

The coefficients b_l have to calculate is such a way that the resulting beampattern complies with the given constraints from eq. 7. This leads to the following set of equations

$$\mathbf{A} \begin{pmatrix} b_1 \\ b_2 \\ \vdots \\ b_{L-1} \\ b_L \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ \vdots \\ 0 \\ 1 \end{pmatrix} , \tag{10}$$

where the coefficients of the matrix $\mathbf{A} = \{a_{k,l}\}_{1 \leq k,l \leq L}$ are calculated by $a_{k,l} = Q(\theta_k, \theta_l)$. Finally the weights can be calculated by the expression

$$w_m = \sum_{l=1}^{L} b_l \cdot g_m(\theta_l) \cdot e^{j\pi(m-1)\sin\theta_l} . \tag{11}$$

This beamformer can also be used for Space-Time-RAKE receiver, where the spatial filtering leads to reduced self interferences of the RAKE-combiner [4].

4 Numerical Results

In this section numerical results on the behavior of the proposed beamformer are given. All investigations were carried out using a linear antenna array consisting of eight microstrip patches which are printed on a joint substrate. The particular element patterns are depicted in fig. 2, wherein the differences between the element patterns become clear. Fig. 3 shows the beampattern of the constrained beamformer using a calibrated vs. an uncalibrated antenna array. The main beam direction was given at $\theta_3 = 40°$ and the nulls are placed at $\theta_1 = -50°$ and $\theta_2 = -10°$. Thereby the given main beam direction is marked with $\diamond$ and the nulls are marked with $\circ$. In this case the calibration of the array means that the steering vector of the array was measured for a large range of angles θ and stored in the array manifold.

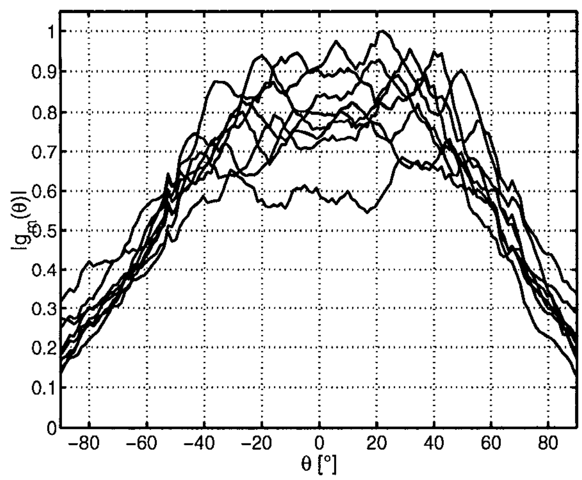

Figure 2: Normalized element pattern of an eight element linear microstrip patch array.

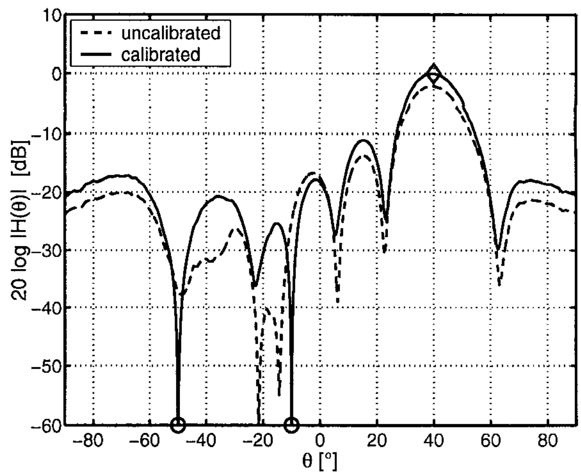

Figure 3: Beampattern with a calibrated vs. an uncalibrated eight element linear microstrip patch array

It can be seen that the beampattern with an uncalibrated antenna array does not fulfill the given constraints. Thereby the positions of the nulls are shifted and the nulls are filled up to relatively slight minima. Thus the uncalibrated beampattern cannot be used for spatial filtering. Using the calibrated antenna array, the constraints are well fulfilled and the nulls achieves very strong attenuation. Using this beampattern a sufficient suppression of disturbing signals can be achieved to realize a performance increase by spatial filtering and/or spatial separation of different subscribers.

5 Conclusions

If very cost effective microstrip antennas are used for SDMA and SFIR applications then the special properties of these antennas have to be considered in order to achieve a maximum performance increase. We have developed a new directivity controlled constrained beamforming algorithm for these antenna arrays, which allows optimum beamsteering and interference cancellation for arbitrarily spaced directions for signals of interest as well as for interfering waveforms. The performance of the beamforming algorithm was compared using a calibrated vs. an uncalibrated real antenna array consisting of eight printed microstrip patch antenna elements. It was demonstrated that the usage of calibrated antenna arrays leads to a very high beamsteering performance.

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