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Abstract

In this paper, we continue our investigation of joint beamforming and transmit diversity with space-time block coding. In particular, the performance of a four-element array antenna is considered, in the context of an indoor wireless communication system. The main contribution is to show that transmit diversity may be practically achieved, even with correlated beams produced by a sparse array antenna.

Keywords

Sparse array antenna, space-time coding, transmit diversity.

1. Introduction

For commercial applications of indoor wireless communications systems, the mobile handset arrays can only be realizable if the number of antenna elements multiplied by the element spacing does not exceed the largest dimension. To give a numerical example, when assuming a carrier frequency of 5 GHz and a conventional spacing between elements of half wavelength, four elements can be considered a practical choice.

However, simple narrowband beamformers with a low number of elements produce beams that are not sharp. In addition, beams created in this manner are *correlated in space*. The values of spatial correlation between beams are strongly dependent on the angles of the beams as well as the angular difference between them [1]. It is important to note that this paper deals with correlation due to overlapping antenna radiation patterns, or beamformer responses. This is not to be confused with fading correlation as defined in [1], which also depends on the scattering environment.

In this paper, the technique introduced in [2] is applied to the case of a sparse array antenna. The key idea is to assign, in accordance to prevailing channel conditions in space and time, a controlled number of beams (either one or two) in conjunction with beam-space-time block coding to achieve transmit diversity. On the receiving end, the cases of both one and two antennas with and without spatial correlation may be considered. Receive spatial correlation is present when a sparse antenna array is used at the handset for diversity purposes and depends mainly on the separation between antenna elements.

2. Beamforming and space-time block coding

The proposed technique may be summarized as follows:

1. Very-fast 180 degrees beam scanning with a *four-element* array antenna.
2. Output power processing of the beamformers to estimate the channel spatial-gain pattern (CSGP).
3. Estimation of the number of beams (either one or two) and their angles.
4. Bits-to-signal mapping and beam-space-time coding and transmission from the handset.
5. A non-frequency-selective block-fading channel is considered, with *correlation between transmission beams*. The correlation coefficients depend on the angles of departure as well as the angular difference between the beams.
6. On the receiving end, estimation and demodulation of the data symbols is performed, with either one or two receive elements. With two elements at the receiver, maximum ratio combining is applied.

As in the precursor paper [2], *space-time block coding* as proposed by Alamouti [3] is employed. In essence, the main idea is to divide the temporal and spatial dimensions and use orthogonal vectors on the transmitter side, so that signals arriving from different beams can be decoupled at the receiver with simple linear processing.

3. Correlation between transmitted beams

In our analysis of the proposed technique, a *transmit correlation matrix*, denoted R, was employed to include the spatial correlation effects between transmit beams. This correlation is the result of having a small number of elements in the handset array producing beams that are no longer sharp. Consequently, the beamformer responses overlap and the signals transmitted by each beam are no longer uncorrelated.

The proposed technique uses a predetermined minimum angular increment, denoted $\Delta\theta$, for the assignment of transmission beams. That is, there are a finite number of choices of angles of departure of the beams. For angles θ

in the range $\Theta = (-\pi/2, \pi/2)$ radians, the correlation matrix has entries $\rho_{j1,j2}$ equal to the spatial correlation between two beams at angles of departure θ_{O1} and θ_{O2}, where $\theta_{Ok} \in \Phi$, for $k = 1,2$.

For a linear antenna array with N elements, the angular response in the frequency domain can be written as

$$H(\theta) = \sum_{n=1}^{N} \omega_n e^{-j2\pi f(n-1)\frac{d}{c}\sin(\theta)}, \qquad (1)$$

where the input to each antenna elements is multiplied by a complex weight ω_n, c is the propagation speed, d is the spacing between elements, f is the carrier frequency and θ is the angle. Let θ_O denote the desired beamformer angle. Then the complex weight associated with the n-th array element is given by

$$\omega_n = e^{j2\pi f(n-1)\frac{d}{c}\sin(\theta_O)}. \qquad (2)$$

To compute the spatial correlation between two different transmit beams with angles of departure, denoted θ_{O1} and θ_{O2}, note that the associated beamformer responses are given, respectively, by the following expressions

$$H_1(\theta) = \sum_{n=1}^{N} \omega_n e^{-j2\pi f(n-1)\frac{d}{c}[\sin(\theta)-\sin(\theta_{O1})]}, \qquad (3)$$

and

$$H_2(\theta) = \sum_{n=1}^{N} \omega_n e^{-j2\pi f(n-1)\frac{d}{c}[\sin(\theta)-\sin(\theta_{O2})]}. \qquad (4)$$

The correlation between two transmit beams with angles of departure θ_{O1} and θ_{O2} is defined as

$$R(\theta_{01}, \theta_{02}) = \int_{-\pi}^{\pi} |H_1(\theta) H_2(\theta)| d\theta. \qquad (5)$$

Evidently, the correlation between two beams is a measure of the overlap between the associated beamformer responses. Figure 1 shows two examples of the normalized (with respect to the maximum value) correlation coefficients as a function of the angle of departure of the second transmitted beam, θ_{02}, for angles of departure of the first transmitted beam, θ_{01}, equal to 0 deg and –50 degrees.

Based on the angles of departure, θ_{01} and θ_{02}, of the transmitted beams, the indexes of the coefficients in the correlation matrix are computed as

$$j_k = \left\lceil \frac{\theta_k}{\Delta \phi} \right\rceil, \qquad (6)$$

for $k = 1,2$, and where $\lceil x \rceil$ denotes the smallest integer greater than or equal to x. These indexes are used to read out the associated correlation coefficient R_{j_1,j_2} from the pre-computed inter-beam correlation matrix R.

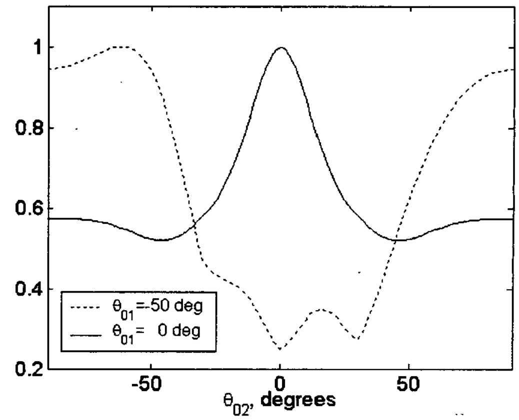

Figure 1. Two examples of beam correlation patterns as functions of the angles of departure of transmitted beams.

4. Channel model

For the purposes of simulating in a computer beamforming and angular spread estimation, the *geometrically based single-bounce* (GBSB) model was employed [4]. This model was selected because it is most appropriate for indoor environments where both transmit and receive antennas have a low height. For simulation purposes whose results are presented in the next section, the parameters of the GBSB model are set as follows: The carrier frequency is equal to 5 GHz, the maximum normalized delay equal to 2, the path loss exponent equal to 4, uniform distribution of the distance between the transmitter and receiver in the range of 10 to 50 meters, and number of multipath components uniformly distributed in the range of 10 to 50. As indicated above, the number of antenna elements in the array was set equal to four.

In the simulations of the spatial channel using the GBSB model and the proposed beam-space-time coding technique, the inter-beam spacing was set equal to $\Delta\theta = 6$ degrees. This is the value used in the steps of 180-degrees scanning of the channel spatial response, output power processing of the beamformers to estimate the channel spatial-gain pattern (CSGP) and estimating of the number of beams (either one or two) and their associated angles of departure. The threshold for determining the transmitted beams selected was set equal to 20 dB. That is, a beam was assigned to a particular angle of departure value whenever the channel response was greater than 20 dB below the maximum channel response. As a result, in all the simulations of the proposed system, two transmitted beams were always assigned.

5. Results

In this section, simulation results are presented on the performance of beamforming and space-time block coding with a sparse array antenna.

Figure 2 is a plot of bit error rate (BER) versus signal to noise ratio per bit, for the case of QPSK modulation and transmit diversity and two correlated beams produced by a four-element antenna. The performance of beam-space-time block coding with the array antenna, with the legend "Correlated", is compared with that of transmit diversity using two uncorrelated antennas, with the legend "Uncorrelated". It is observed that not all the potential diversity factor can be obtained, although, perhaps surprisingly, the perfomance of the sparse array is better than that of two uncorrelated antennas at BER above 0.001.

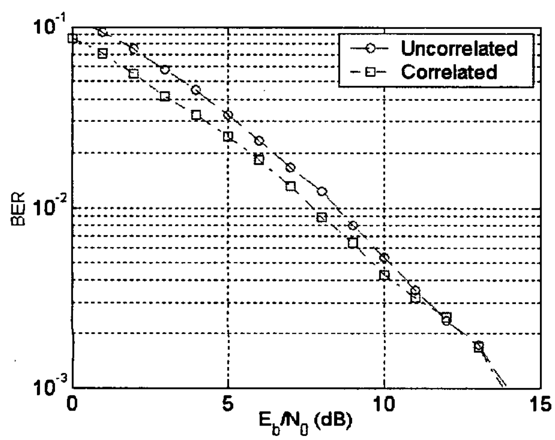

Figure 2. Performance of beamforming and space-time block coding with: (i) a sparse array antenna (Correlated) and (ii) two uncorrelated antennas (Uncorrelated).

In Figure 3 the BER performance of the proposed technique is shown, as a function of the number of receive antennas. Maximum ratio combining is employed. As expected, the diversity factor doubles with the employment of two uncorrelated receive antennas.

6. Conclusions and final remarks

In this paper, the performance of a beam-space-time coding technique with a sparse array antenna of four elements was evaluated. It was shown that a small loss in diversity factor is experienced, resulting in a good compromise between physical size and error performance. Current research activities include the study of other array geometries and the performance of a sparse array antenna for the purposes of *receive diversity*, where spatial correlation is present.

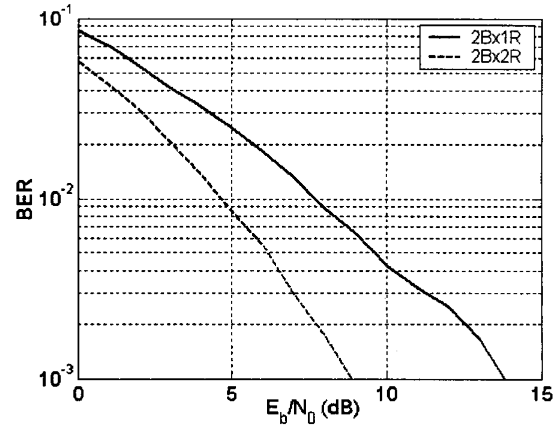

Figure 3. Performance of beamforming and space-time block coding with one (legend "2Bx1R") and two (legend "2Bx2R") receive antennas.

Acknowledgments

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