Noncoherent Eigenbeamforming for a Wideband Cellular Uplink

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We investigate wideband space-time communication on the uplink of an outdoor cellular system, in which the base station is equipped with N antennas and the mobile has a single antenna. We assume noncoherent reception at the base station, which incurs significantly less overhead than pilot-based estimation of the space-time channel from each mobile to the base station. Noncoherent communication techniques are particularly well suited to outdoor cellular systems for which channel time variations are significant due to mobility at vehicular speeds. As is common in outdoor cellular systems, we assume little or no scattering around the base station, so that, from the viewpoint of the base station antenna array, the incoming signal from a given mobile has a narrow power angle profile. Thus, the spatial channel covariance matrix is typically highly colored, having one or two dominant eigenmodes. We demonstrate that large beamforming gains are achievable without explicit estimation of the space-time channel, while only processing a relatively few number of dominant eigenmodes.

Consider the received signal Y_f at frequency bin f in an OFDM system (1). The $N \times 1$ space-time channel H_f for each subcarrier is well-modeled as identically distributed complex Gaussian random vectors that decorrelate across frequency [1].

$$Y_f = H_f x + W_f \tag{1}$$

Thus, the spatial covariance matrix $C = E[H_f H_f^\dagger]$ can be obtained by averaging over subcarriers, without requiring any pilot overhead. A spectral decomposition of the channel co-

$$C = U \Lambda U^\dagger \tag{2}$$

variance matrix yields (2), where the eigenvector matrix $U = [U_1 \dots U_N]$ is unitary, and Λ is diagonal with eigenvalues $\{\lambda_l\}$ arranged in decreasing order. The eigenvalue λ_l represents the strength of the channel on l^{th} eigenmode U_l.

We propose an *eigenbeamforming* receiver that projects the received signal in each subcarrier along the L (typically much smaller than the number of receive elements N) dominant eigenmodes of the estimated channel covariance matrix, $\{U_l\}_{l=1}^{L}$. Beamforming along the dominant eigenmodes of the channel creates parallel, independently fading channels for the same transmitted data. For each of the L eigenmodes, we employ noncoherent coded modulation strategies with turbo-like joint data and channel estimation, as in prior work on single antenna channels [2, 3, 4]. Thus, by appropriately leveraging the covariance estimate available in a wideband system, the noncoherent eigenbeamforming receiver provides many of the benefits of explicit space-time channel estimation without incurring its overhead. For example, beamforming gains in received SNR (relative to a single antenna system) are realized, while incurring reasonable complexity by using a small number of dominant eigenmodes for demodulation and decoding.

In addition to an SNR advantage from scaling up the number of receive elements, diversity gains are provided by the L parallel, independent fading channels. To the end of quantifying noncoherent eigenbeamforming diversity gain, we have computed the capacity with QPSK signaling of L parallel block fading channels of possibly unequal strengths. Information-theoretic computations similar to those in [5] show that the capacity is relatively insensitive to the number of dominant eigenmodes at low SNR, while there is a diversity gain of up to 2 dB at high SNR. Thus, the penalty due to the relatively few spatial eigenmodes for outdoor channels is small for OFDM systems, assuming that there is enough averaging across frequency and time.

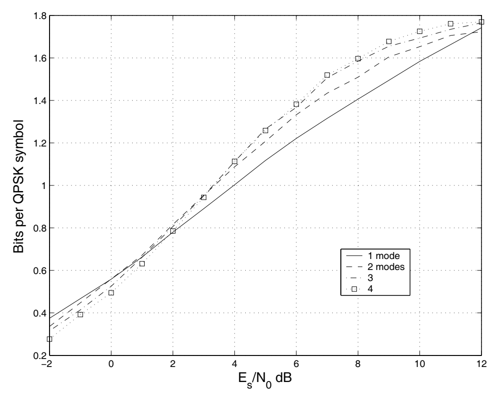

Figure 1: Block fading capacity with varying number of dominant, equal-strength eigenmodes

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