Analyzing the Performance of Hybrid Diversity-Beamforming Systems in Spatially Correlated Channels

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Abstract

In this paper, we analyze the performance of a hybrid multi-antenna system that combines the diversity and beamforming techniques. We consider a new hybrid system that clusters the transmission antennas into an arbitrary number of groups with each group formed by a multitude of adjacent antennas. We employ the diversity technique among different groups and the beamforming technique within each group. In this system, we balance the trade-offs between the diversity and beamforming techniques by controlling the number of groups. We present a generalized performance analysis of the hybrid diversity-beamforming systems that is applicable to the cases with arbitrary antenna spacing and angular spread. We compare the performance of the diversity, beamforming, and hybrid systems in terms of the outage probability and ergodic capacity. We show through numerical results that the optimally designed hybrid system yields the lowest outage probability among the three systems while providing an ergodic capacity comparable to the beamforming system in partially correlated fading channels.

I. INTRODUCTION

Recently, the multi-antenna systems that use multiple transmit antennas at the base station have emerged as an attractive topic for research. For such systems, two representative transmission technologies have been developed for efficient utilization of antennas: One is the transmit diversity technique that enables more reliable transmission by transmitting signals through multiple channels, and the other is the transmit beamforming technique that increases the received signal power by steering the antenna beam-pattern to a particular direction. These two techniques are known to have somewhat opposite but complementary characteristics. According to Friedlander and Scherzer [1], beamforming performs better than diversity in terms of outage capacity and transmission power when fadings at different antennas are highly correlated, while diversity outperforms beamforming in the case of independent fading channels.

In order to take advantage of the desirable features of both diversity and beamforming, Soni *et al.* [2] proposed a new hybrid antenna architecture that realized diversity by spacing two different groups of antennas far apart and realized beamforming as well by spacing antennas within each group closely together. Nezafat and Kaveh [3] analyzed the performance of this hybrid system for the special case where fadings at different groups are independent while those at different antennas within a single group are fully correlated.

In this paper, we analyze the performance of the hybrid diversity-beamforming systems in more general context. We consider a new hybrid system that clusters the transmission antennas into an arbitrary number of groups with each group formed by a multitude of adjacent antennas. Similarly to [2], we employ the diversity technique among different groups and the beamforming technique within each group. In this system, we balance the trade-offs between the diversity and beamforming techniques by controlling the number of groups: The optimal number of groups may be chosen such that it maximizes the performance in terms of ergodic capacity or outage probability. Such performance metrics depend mainly on the spatial correlation, which in turn is determined by the antenna spacing and angular spread. So we present a generalized performance analysis of the hybrid diversity-beamforming systems that is applicable to the cases with arbitrary antenna spacing and angular spread. Based on this analysis, we demonstrate that the optimally designed hybrid system can achieve a lowest level of outage probability while maintaining ergodic capacity comparable to the beamforming system in partially correlated fading channels.

II. SYSTEM MODEL

We consider a point-to-point communication link with M transmit antennas and a single receive antenna. We denote by h_m the channel gain between transmit antenna m, $m = 1, 2, \ldots, M$, and the receive antenna.

Assuming that antenna elements are spaced uniformly, the channel gain is given by

$$h_m(\theta) = \alpha e^{j2\pi(m-1)\frac{d}{\lambda}\sin\theta}, \quad (1)$$

where α is a complex, zero-mean, unit variance Gaussian-random variable with independent real and imaginary parts, d the spacing between the antennas, λ the carrier wavelength, and θ the direction of arrival. We denote by $\mathbf{h}(\theta)$ the vector of the channel gains, i.e., $\mathbf{h}(\theta) = [h_1(\theta), \cdots, h_M(\theta)]^T$

The correlation among the channel gains at different antennas depends on the multipath angular distribution of

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