Quantized Antenna Weighting Codebook Design for Multiple-Input Multiple-Output Wireless Systems

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1 Introduction

Multiple antenna wireless systems are of practical interest because of their ability to provide improved capacity over single antenna wireless systems [1]. Weighting of sufficiently spaced antennas has long been used in receive diversity combiners for single-input multiple-output (SIMO) wireless systems [2]. When the transmitter has channel knowledge, the extension of the SIMO weighting method to multiple-input single-output (MISO) systems is straightforward due to the fact that both systems encounter vector channels. The design methods used for vector channels can not be directly applied to the matrix channels encountered in multiple-input multiple-output (MIMO) wireless systems [3]. Transmission weighting techniques such as maximum ratio transmission (MRT) [4], equal gain transmission (EGT) [3], and selection diversity transmission (SDT) [5] have all been extended to the case of MIMO wireless systems.

MIMO weighting schemes require perfect channel information to design the the transmit weights. In many systems such as frequency division duplexing systems, the transmitter will have little to no knowledge of the actual downlink channel. Quantized antenna weighting schemes have previously been proposed ([6],[7]) as a solution to this problem. In these schemes the receiver, which is assumed to have a perfect channel estimate, picks a transmit weight vector and sends the quantized weight vector to the transmitter on a limited feedback channel. Quantized systems can be interpreted [7] as systems where the receiver chooses one vector within an N vector codebook, that both the transmitter and receiver have access to, and sends the codebook label of this vector to the transmitter.

Previous quantized transmit diversity schemes used vector quantization methods to design codebooks. While this process yields excellent codebooks, it is computationally intensive and does not yield intuition on what constitutes a "good" codebook. In this paper, we derive a codebook design criteria based on maximizing the average receive signal-to-noise ratio (SNR). The criteria is based on the MIMO Rayleigh fading channel model.

2 Quantized Antenna Weighting

We assume the received symbol at the output of the combiner can be written as

$$y = \mathbf{z}^*\mathbf{H}\mathbf{w}s + \mathbf{z}^*\mathbf{n} \tag{1}$$

where $\mathbf{z}$ denotes the M_r-length receive weight vector, $\mathbf{w}$ denotes the M_t-length transmit weight vector, $\mathbf{H}$ represents a matrix of independent entries each distributed according to $\mathcal{C}N(0,1)$, s is the transmitted symbol, and $\mathbf{n}$ is a noise vector with independent entries distributed accoding to $\mathcal{C}N(0,N_0)$. We assume a maximum ratio combiner, i.e. $\mathbf{z} = \mathbf{HW}/\|\mathbf{Hw}\|_2$, meaning that the receive SNR is given by $\Gamma_r \mathcal{E}_t/N_0$ where $\mathcal{E}_t$ is the transmit energy and $\Gamma_r = \|\mathbf{Hw}\|_2^2$. Thus with fixed $\mathcal{E}_t$ and N_0 to maximize the receive SNR we must maximize $\|\mathbf{Hw}\|_2$.

When $\mathbf{H}$ is MIMO Rayleigh fading, it can be shown [8] that an optimal weight vector is distributed uniformly on the M_t dimensional complex unit sphere. As well note that $\|\mathbf{H}e^{j\theta}\mathbf{W}\| = \|\mathbf{Hw}\|$, so any unit gain multiple of the an optimal weight vector is also optimal. Therefore, we want to quantize the complex unit sphere with a phase invariant minimum mean square error quantizer. We conjecture that the optimal quantizer for a uniform source such as this is the set of N maximally spaced vectors (defining spacing in terms of absolute correlation). This is equivalent to the problem of Grassmannian line packing.

This leads to a design criteria for quantized antenna weighting codebooks. Let $\mathbf{V}$ be a codebook matrix, meaning that each column $\mathbf{v}_i$ is a codebook vector.

Criteria: The smaller $\max_{i,j:i\neq j} |\mathbf{v}_i^* \mathbf{v}_j|$ the better the quantized antenna weighting codebook.

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