A Channel Estimation Algorithm for MIMO-SCFDE

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***Abstract*—This letter proposes a novel method for channel estimation in a single-carrier multiple input-multiple output (MIMO) system with frequency-domain equalization/detection. To this end, we construct novel short MIMO training sequences that have constant envelope in the time domain to preclude the peak-to-average power ratio problem encountered in many systems that utilize the frequency domain for data recovery. Simultaneously, the spectrum in the frequency domain is flat except for a grid of nulls for predefined frequency tones. Armed with these sequences, we provide an algorithm that is optimal in the least squares (LS) sense at a potentially low computational cost. Results show that the algorithm performs identically to other proposed LS techniques. Furthermore, the algorithm is extremely bandwidth efficient in that the total training overhead required to obtain full CSI is just one block.**

***Index Terms*—Channel estimation, MIMO, OFDM, SCFDE.**

I. Introduction

A VERY popular low-complexity broadband technique that has seen extensive research in the past decade is orthogonal frequency-division multiplexing (OFDM). Lately, however, much attention has been focused on another broadband technique, namely single-carrier (SC) transmission with frequency-domain equalization (FDE). SCFDE systems promise equal complexity and performance to OFDM systems without the high peak-to-average power ratio (PAPR) problem that plagues OFDM systems [1], [2]. Although channel estimation in OFDM systems has been studied extensively in both the single and multiantenna cases (e.g., see [3] and references therein), this topic has been left relatively unaddressed for SCFDE systems.

Typically, multiple input-multiple output (MIMO) channels are estimated by transmitting orthogonal training sequences in conjunction with least squares (LS) or minimum mean-square error (MMSE) methods. In [4], a recursive reconstructive (RR) channel estimation method based on novel training sequences was proposed for MIMO-SCFDE systems. In this letter, we eliminate the recursive process described in [4], thereby reducing the complexity of estimating the channel while maintaining bandwidth efficiency. For most practical cases, the algorithm is in fact a computationally efficient method of meeting the LS criterion.

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II. System and Channel Description

Consider a wideband MIMO-SCFDE system with n_T transmit antennas and n_R receive antennas in which a length-N baseband sequence is modulated onto a SC waveform at each transmit antenna for transmission across a wireless channel. The received baseband sequences are equalized in the frequency domain. A cyclic prefix is added to each sequence prior to transmission and removed from each of the received sequences. We assume that the cyclic prefix is greater than or equal to the channel memory order, thereby preventing interblock interference and aiding the equalization process.

Let $\mathbf{t}_q$ be the length-N time domain training sequence transmitted from antenna q, and let $\mathbf{h}_{p,q}$ be a length-N column vector that denotes the complex frequency response of the channel between transmit antenna q and receive antenna p. We denote the channel coefficient on the nth tone by $h_{p,q;n}$. The entire channel can be represented by the vector $\underline{\mathbf{h}} = [\mathbf{h}_{1,1}^T, \mathbf{h}_{1,2}^T, \ldots, \mathbf{h}_{n_R,n_T}^T]^T$.

An N-point discrete Fourier transform (DFT) is employed at each receive antenna in a MIMO-SCFDE system prior to equalization. In the frequency domain, the received signal at the pth antenna on the nth tone can be mathematically described by

$$y_{p;n} = \sum_{q=1}^{n_T} h_{p,q;n} x_{q;n} + \eta_{p;n} \tag{1}$$

where $x_{q;n}$ denotes the nth tone of the training sequence transmitted from the qth antenna and the noise term $\eta_{p;n} \sim \mathcal{CN}(0,\sigma^2)$[1]. As shown in (1), the signal received at the pth antenna is a superposition of all of the transmitted training signals, which complicates symbol detection and training. For data detection, the received signal is equalized and transformed back into the time domain with an inverse DFT (IDFT). For channel estimation, however, the proposed algorithm can be employed following the DFT as described in the next section.

III. Channel Estimation for MIMO-SCFDE

The advantage of using this algorithm is that it allows the transmitted sequence to be nulled on certain frequency tones, causing the transmitted training sequences to be orthogonal in the frequency domain. Thus, (1) reduces to

$$y_{p;n} = h_{p,q;n} x_{q;n} + \eta_{p;n}, \quad n \in \mathbf{\Omega}_q \tag{2}$$

where $\mathbf{\Omega}_q$ is the set of tones over which training data is transmitted from the qth antenna. The nulled tones are then reconstructed at the receiver to provide a full channel estimate by executing the following steps for each channel path to reconstruct the entire frequency response:

[1] $\mathcal{CN}$ denotes the complex normal distribution.